Appendix A

WHAT DO THOSE TECHNICAL TERMS MEAN?

MEASURES OF EARTHQUAKE MAGNITUDE AND INTENSITY

Earthquakes commonly are "measured" by use of two different scales – the *Richter magnitude scale* and the *modified Mercalli intensity scale.* As these two names indicate, one scale measures *magnitude* while the other indicates the *intensity* of the earthquake motion at specific places around the earthquake epicenter. Since both scales measure very different things, they cannot really be related to one another or compared. However, since both are used, the concerned individual should have a general understanding of both.

RICHTER MAGNITUDE

The Richter magnitude scale was developed by Charles F. Richter in 1935. It is defined as the logarithm to the base of 10 of the maximum trace amplitude in millimeters as recorded on a standard seismograph located 100 kilometers (or 62 miles) from the earthquake epicenter.

A Richter scale measurement is expressed in whole and decimal numbers and it can be used to identify the magnitude of an earthquake and estimate how much energy was released. In this context, it is important to remember that the Richter scale is logarithmic and, therefore, each unit of increase on the scale reflects a 10 times increase in amplitude. This represents approximately a 32-fold increase in energy released. Thus, an earthquake of Richter magnitude 8.3 would have an amplitude of 10,000 times that of an earthquake of Richter Magnitude 4.3 and would release approximately 1,050,000 times more energy.

As originally developed by Richter, this magnitude scale applied to Southern California shallow earthquakes located less than 375 miles from the recording instrument. Now, however, it is commonly used to compare earthquakes worldwide and at distances much farther from the recording instrument. Other magnitude scales have been developed that more accurately describe the variety of earthquakes that may be encountered, and the Richter magnitude scale is now recommended only for measuring earthquakes between about magnitudes 3 and 7. For the larger earthquakes that are of particular concern for seismic design, the *moment magnitude* (M_w) scale is now used by the U.S. Geological Survey and others. Moment magnitude is a combination of the *rigidity of the rock times the area of faulting times the amount of slippage*; this scale is based on the forces that work at the fault rupture to produce the earthquake rather than the recorded amplitude of seismic waves and is directly related to the energy released by the earthquake.

Moment magnitude, however, can be assigned only after considerable study of the geology and size of the fault rupture, while the Richter magnitude is almost immediately available after the shock. Thus, the Richter magnitude will continue to be a useful comparative index of earthquake size, even though, because of its limitations, it does not give an accurate measure of the earthquake effects in terms of damage.

Note that deep earthquakes more characteristic of the eastern United States are best compared by measuring their *P-waves*, which are not affected by the depth of the source. This measurement is referred to as *body-wave magnitude* (m_b).

MODIFIED MERCALLI INTENSITY SCALE

As noted, use of Richter magnitude gives little indication of earthquake intensity and building damage. The first scale created to do this was developed in the 1880s by the Italian *de Rossi* and the Swiss *Forel*. It was modified in 1902 by the Italian *Mercalli* and later further modified a number of times. A version of the Rossi-Forel scale generally is used in Europe while the modified Mercalli intensity (MMI) scale is used in the United States.

The following excerpt from Bruce A. Bolt's 1978 book, *Earthquakes: A Primer* (W. H. Freeman and Company, San Francisco, California), describes modified Mercalli intensity values (1956 version):

I. Not felt. Marginal and long period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks or sensation of a jolt like a heavy ball striking the walls. Standing cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frames creak.

V. Felt outdoors; directions estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture overturned. Weak plaster, Masonry D cracked. Small bells ring (church and school), Trees, bushes shaken visibly or heard to rustle.

VII. Difficult to stand. Noticed by drivers. Hanging objects quiver. Furniture broken. Damage to Masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, also unbraced parapets, and architectural ornaments. Some cracks in Masonry C. Waves on ponds, water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of cars affected. Damage to masonry C; partial collapse. Some damage to Masonry B; none to Masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; Masonry C heavily damaged, sometimes with complete collapse; Masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted down, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in the ground. In alluviated areas, sand and mud ejected, earthquake fountains and sand craters.

X. Most masonry and frame buildings destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serous damage to dams, dikes, embankments.

Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown in the air.

Note that the masonry definitions used are from C. F. Richter's 1958 book, *Elementary Seismology* (W. H. Freeman and Company, San Francisco, California), and are as follows: Masonry A – good workmanship, mortar, and design; reinforced, especially laterally; bound together by using steel, concrete etc; designed to resist lateral forces. Masonry B – good workmanship and mortar; reinforced but not designed in detail to resist lateral forces. Masonry C – Ordinary workmanship and mortar, no extreme weaknesses like failing to tie in at corners but not reinforced or designed against horizontal forces. Masonry D – weak materials such as adobe, poor mortar, low standards of workmanship; weak horizontally.

Unlike the Richter magnitude scale, whose values are set by instrumented readings, the Mercalli scale is subjective and values are set by observers based on interpretation of the above indicators. A problem with the Mercalli scale is that, due to its age, it has no references to modern structural types of reinforced concrete, steel, etc. On the other hand, since older buildings are most prone to damage, this limitation may not be too serious.

It should be noted that a given earthquake will have one Richter magnitude (once the various seismological stations agree) but will have a number of Mercalli intensities depending on the distance from the epicenter.

TERMINOLOGY

Acceleration – Rate of change of velocity with time.

Amplification – A relative increase in ground motion between one type of soil and another or an increase in building response as a result of resonance.

Amplitude – Maximum deviation from mean of the center line of a wave.

Architectural Components – Components such as exterior cladding, ceilings, partitions, and finishes.

Component (also Element) -- Part of an architectural, structural, electrical, or mechanical system.

Configuration – The size, shape, and geometrical proportions of a building.

Connection – A method by which different materials or components are joined to each other.

Damage – Any physical destruction caused by earthquakes.

Deflection – The state of being turned aside from a straight line, generally used in the horizontal sense; see also "Drift."

Design Earthquake – In the *Provisions*, the earthquake that produces ground motions at the site under consideration that has a 90 percent probability of not being exceeded in 50 years (or a 10 percent probability of being exceeded).

Design Ground Motion – See "Design Earthquake."

Diaphragm – A horizontal or nearly horizontal structural element designed to transmit lateral forces to the vertical elements of the seismic force resisting system.

Drift – Vertical deflection of a building or structure caused by lateral forces; see also "Story Drift."

Ductility – Property of some materials, such as steel, to distort when subjected to forces while still retaining considerable strength.

Earthquake – A sudden motion or vibration in the earth caused by the abrupt release of energy in the earth's lithosphere.

Effective Peak Acceleration and *Effective Peak Velocity-Related Acceleration* – Coefficients shown on maps in the *Provisions* for determining prescribed seismic forces.

Elastic – Capable of recovering size and shape after deformation.

Epicenter – A point on the earth's surface that is directly above the focus of an earthquake.

Exceedance Probability – The probability that a specified level of ground motion or specified social or economic consequences of earthquakes will be exceeded at a site or in a region during a specified exposure time.

Exposure – The potential economic loss to all or certain subsets of the built environment as a result of one or more earthquakes in an area; this term usually refers to the insured value of structures carried by one or more insurers.

Fault – A fracture in the earth's crust accompanied by displacement of one side of the fracture with respect to the other in a direction parallel to the fracture.

Focus – The location of a fault break where an earthquake originates; also termed "hypocenter."

Force – Agency or influence that tries to deform an object or overcome its resistance to motion.

Frame, Braced – Diagonal members connecting together components of a structural frame in such a way as to resist lateral forces.

Frame System, Building – A structural system with an essentially complete space frame providing support for vertical loads; seismic forces are resisted by shear walls or braced frames.

Frame System, Moment – A space frame in which members and joints are capable of resisting lateral forces by bending as well as along the axis of the members; varying levels of resistance are provided by ordinary, intermediate and special moment frames as defined in the *Provisions* with special frames providing the most resistance.

Frame, Space – A structural system composed of interconnected members, other than bearing walls, that is capable of supporting vertical loads and that also may provide resistance to seismic forces.

"g" – The acceleration due to gravity or 32 feet per second per second.

Ground Failure – Physical changes to the ground surface produced by an earthquake such as lateral spreading, landslides, or liquefaction.

Hypocenter – See "Focus."

Intensity – The apparent effect that an earthquake produces at a given location; in the United States, intensity generally is measured by the modified Mercalli intensity (MMI) scale.

Irregular – Deviation of a building configuration from a simple symmetrical shape.

Joint – Location of connections between structural or nonstructural members and components.

Liquefaction – The conversion of a solid into a liquid by heat, pressure, or violent motion; sometimes occurs to the ground in earthquakes.

Load, Dead – The gravity load created by the weight of all permanent structural and nonstructural building components such as walls, floors, roofs, and fixed service equipment.

Load, Live – Moving or movable external loading on a structure; it includes the weight of people, furnishings, equipment, and other items not permanently attached to the structure.

Loss – Any adverse economic or social consequences caused by earthquakes.

Mass – A constant quantity or aggregate of matter; the inertia or sluggishness that an object, when frictionlessly mounted, exhibits in response to any effort made to start it or stop it or to change in any way its state of motion.

Mercalli Scale (or Index) – A measure of earthquake intensity named after Giuseppe Mercalli, an Italian priest and geologist.

Partition – See "Wall, Nonbearing."

Period – The elapsed time (generally in seconds) of a single cycle of a vibratory motion or oscillation; the inverse of frequency.

P-Wave – The primary or fastest waves traveling away from a fault rupture through the earth's crust and consisting of a series of compressions and dilations of the ground material.

Recurrence Interval – See "Return Period."

Resonance – The amplification of a vibratory motion occurring when the period of an impulse or periodic stimulus coincides with the period of the oscillating body.

Return Period – The time period in years in which the probability is 63 percent that an earthquake of a certain magnitude will recur.

Richter Magnitude (or Scale) – A logarithmic scale expressing the magnitude of a seismic (earthquake) disturbance in terms of the maximum amplitude of the seismic waves at a standard distance from their focus named after its creator, the American seismologist Charles R. Richter.

Rigidity – Relative stiffness of a structure or element; in numerical terms, equal to the reciprocal of displacement caused by unit force.

Seismic – Of, subject to, or caused by an earthquake or an earth vibration.

Seismic Event – The abrupt release of energy in the earth's lithosphere causing an earth vibration; an earthquake.

Seismic Forces – The actual forces created by earthquake motion; assumed forces prescribed in the *Provisions* that are used in the seismic design of a building and its components.

Seismic Hazard – any physical phenomenon such as ground shaking or ground failure associated with an earthquake that may produce adverse effects on the built environment and human activities; also the probability of earthquakes of defined magnitude or intensity affecting a given location.

Seismic Hazard Exposure Group – A classification assigned in the *Provisions* to a building based on its occupancy and use.

Seismic Performance Category – A classification assigned in the *Provisions* based on its Seismic Hazard Exposure Group and its seismic hazard.

Seismic Force Resisting System – The part of the structural system that is designed to provide required resistance to prescribed seismic forces.

Seismic Risk – The probability that the social or economic consequences of an earthquake will equal or exceed specified values at a site during a specified exposure time; in general, seismic risk is vulnerability multiplied by the seismic hazard.

Seismic Waves – See "Waves, Seismic."

Seismic Zone – Generally, areas defined on a map within which seismic design requirements are constant; in the *Provisions*, seismic zones are defined both by contour lines and county boundaries.

Shear – A force that acts by attempting to cause the fibers or planes of an object to slide over one another.

Shear Panel – See "Wall, Shear."

Shear Wall – See "Wall, Shear."

Speed – Rate of change of distance traveled with time irrespective of direction.

Stiffness – Resistance to deflection or drift of a structural component or system.

Story Drift – Vertical deflection of a single story of a building caused by lateral forces.

Strain – Deformation of a material per unit of the original dimension.

Strength – The capability of a material or structural member to resist or withstand applied forces.

Stress – Applied load per unit area or internal resistance within a material that opposes a force's attempts to deform it.

S-Wave – Shear or secondary wave produced essentially by the shearing or tearing motions of earthquakes at right angles to the direction of wave propagation.

System – An assembly of components or elements designed to perform a specific function such as a structural system.

Torque – The action of force that tends to produce torsion; the product of a force and lever arm as in the action of using a wrench to tighten a nut.

Torsion – The twisting of a structural member about its longitudinal axis.

Velocity – Rate of change of distance travelled with time in a given direction; in earthquakes, it usually refers to seismic waves and is expressed in inches or centimeters per second.

Vulnerability – The degree of loss to a given element at risk, or set of such elements, resulting from an earthquake of a given intensity or magnitude; expressed in a scale ranging from no damage to total loss; a measure of the probability of damage to a structure or a number of structures.

Wall, Bearing – An interior or exterior wall providing support for vertical loads.

Wall, Nonbearing – An interior or exterior wall that does not provide support for vertical loads other than its own weight as permitted by the building code; see also "Partition."

Wall, Shear – A wall, bearing or nonbearing, designed to resist seismic forces acting in the plane of the wall.

Wall System, Bearing – A structural system with bearing walls providing support for all or major portions of the vertical loads; seismic resistance may be provided by shear walls or braced frames.

Waves, Seismic – Vibrations in the form of waves created in the earth by an earthquake.

Weight – Name given to the mutual gravitational force between the earth and an object under consideration; varies depending on location of the object at the surface of the earth.

GENERAL TERMS

The following excerpt from the National Research Council Report, *Multiple Hazard Mitigation* (Washington, D.C.: National Academy Press, 1983), defines several other terms that sometimes cause confusion in discussions of seismic safety:

> ". . . The level of intensity or severity that is capable of causing damage depends upon the vulnerability of the exposed community; vulnerability is generally a function of the way in which structures are designed, built, and protected, and the vulnerability of a structure or community to a particular natural event is a measure of the damage likely to be sustained

should the event occur. The degree to which a community is prone to a particular natural hazard depends on risk, exposure, and vulnerability. When a natural hazard occurrence significantly exceeds the community's capacity to cope with it, or causes a large number of deaths and injuries or significant economic loss, it is called a disaster.

Hazard management includes the full range of organized actions undertaken by public and private organizations in anticipation of and in response to hazards. Hazard management has two primary (but not completely distinct) components: emergency management, typified by the police, fire, rescue, and welfare work carried on during a disaster; the advance planning and training that are necessary if emergency operations are to be carried out successfully; and the post-disaster recovery period in which damage is repaired; and mitigation, which focuses on planning, engineering, design, economic measures, education, and information dissemination, all carried out for the purpose of reducing the long-term losses associated with a particular hazard or set of hazards in a particular location."

Appendix B

BUILDING REGULATION IN THE UNITED STATES

INTRODUCTION

The regulation of building construction has been a matter of public concern from the beginning of civilization. An early building code provision can be found in the *Old Testament*:

> "When you build a new house you shall make a parapet for your roof that you may not bring the guilt of blood upon your house if anyone fall from it."

This provision has remained relatively intact for 4000 years and is now (in less emotional language) Section 1711 of the *Uniform Building Code*, which reads:

> "All unenclosed floor and roof openings . . . and roof used for other than service of the building shall be protected by a guard rail."

Building regulation reflects the fundamental duty of government to protect people and property from harm within the concept of *police power* – the right of all states to protect the general health, safety and welfare through appropriate legislation. In the United States, building regulations generally are an expression of the police power of government, which the *Constitution* has reserved for the states.

Most states have delegated this function in whole or in part to their political subdivisions (cities, counties, villages, towns, and other special districts). Therefore, the building regulatory system is predominantly an aspect of local *home rule* and has evolved with different traditions and to different degrees in various localities and regions. Even today, building remains unregulated in some parts of the United States in deference to the perceived right of property owners to build as they wish on their own land.

If a community decides that it should have a building code, it can:

- Develop its own code,
- Adopt one of the three available national model codes in its entirety. (The model codes are described later in this appendix), or
- Develop its own code by modifying a model code to reflect specific local concerns.

THE PURPOSE OF BUILDING REGULATION

The specific purposes of building regulations usually are set forth clearly in the code or operative legal document of a jurisdiction. In order to understand building regulations, it is essential to realize that they are *minimum legal criteria for construction that can establish both criminal and civil liability* for noncompliance. The specific goals and objectives of building regulatory systems generally are to:

- Prevent or minimize bodily injury to building users and occupants,

- Prevent or minimize structural failures and collapse with attendant injuries to the public and damage to property,

- Prevent or minimize the incidence of fire damage and spread both for individual structures and the community as a whole,

- Prevent or minimize deterioration and damage to property from the elements,

- Prevent or minimize "overcrowding" and the creation of slum and ghetto community conditions, and

- Protect the public welfare as this concept is further defined in local community and/or state law.

Starting from this basic list, the concept of public welfare in relation to U.S. building regulations has been expanded by the courts significantly during the past 25 years. Building regulations and codes now often include detailed provisions for other than safety objectives (for example, accessibility for the disabled, historic preservation, energy conservation, and noise control). Some broader environmental concerns (for example, air and water pollution), economic development issues, and aesthetic considerations also have found their way into some building regulations under the aegis of the police power protection within an expanded concept of public welfare.

PARTICIPANTS IN THE REGULATORY PROCESS

The principal participants in the U.S. regulatory system are:

- Local government building and safety departments and special districts,

- State agencies (both regulatory and proprietary interests),

- Federal agencies (both regulatory and proprietary interests), and

- Model code organizations, professional societies, and building industry and trade associations.

LOCAL GOVERNMENT BUILDING AND SAFETY DEPARTMENTS AND SPECIAL DISTRICTS

Enforcement of the building regulatory system for some 75 percent of construction activity emanates from local jurisdictions that issue permits and inspect private projects for conformance. The content and detail of these building regulations are developed, however, in a more complex regional and/or national context and process.

Separate from local regulatory jurisdictions are a large number and variety of local special-purpose districts (for example, schools and utilities). The state or regional enabling legislation for these special districts often makes them autonomous authorities and exempts them from local regulatory controls; thus, they may develop their own building regulations for their programs, which may cross local regulatory jurisdictional boundaries.

STATE AGENCIES

Many states, in response to either lack of uniformity in or the absence of local building regulations, have enacted parallel sets of statewide minimum regulations for selected classifications of private buildings (for example, housing or high-rise structures). These statewide regulations reflect a multitude of state organizational formats and legislative backgrounds and often serve as a screening device for state lending, insurance, and other indirect funding programs and mechanisms.

Virtually all states also have agencies that construct, regulate, and maintain state-owned and -operated facilities (for example, schools, correctional facilities, and hospitals). These agencies also often are exempt from local regulations and develop types of internal building regulations for their programs and projects.

Although most state agencies have the authority to write their own building regulations, as a practical matter they usually adopt some form of the model code in current general use in the region, incorporating additions and amendments to reflect specific state concerns.

FEDERAL AGENCIES

Like the states, agencies of the federal government are exempt from the home rule concept of U. S. building regulations. Although the trend is for these agencies to use existing national standards whenever possible, over the years they have developed extensive internal building regulations to address their own proprietary construction interests. In some cases, federal agencies have developed or adopted forms of building regulations as direct qualifying standards for federal funding of private sector construction or for indirect funding through redevelopment and other subsidy programs.

Other federal agencies are directly involved in either developing and writing building regulations and standards or providing technical assistance to and research for those organizations that do write and promulgate them. Many of these agencies participate on the Interagency Committee on Seismic Safety in Construction (ICSSC).

Two recent executive orders impose new directives on the federal government. With respect to new construction, Executive Order 12699 requires that new buildings be designed and constructed to meet the requirements of either the latest edition of the *NEHRP Recommended Provisions* or the immediately preceding edition. Executive Order 12941 directs federal agencies to evaluate existing federally owned and leased buildings to identify buildings that are potentially hazardous and to plan for the seismic rehabilitation of those so identified.

MODEL CODE ORGANIZATIONS, PROFESSIONAL SOCIETIES AND INDUSTRY AND TRADE ORGANIZATIONS

Currently the following three model code organizations are active in the United States and produce model sets of basic building regulations:

- The Building Officials and Code Administrators International (BOCA),
- The International Conference of Building Officials (ICBO), and
- The Southern Building Code Congress International (SBCCI).

These model code organizations have regional bases – BOCA produces building and other codes focusing on the Northeast and Midwest, SBCCI produces similar codes for the South and Southeast, and ICBO produces codes for the West and Midwest. In addition, the National Fire Protection Association (NFPA) produces electrical and fire protection codes that are generally used nationwide. All these organizations publish code documents and offer a variety of other educational and support services that assist local jurisdictions.

The model code organizations are structured as nonprofit, membership-owned corporations. Through appropriate bylaws and voting processes, they develop, publish, and modify building regulations in response to changing building technology and experience. A published model code usually is adopted by reference by a local jurisdiction's legislative body.

The building design professions (architects and engineers) have a long-standing tradition of active professional interest in the building regulatory system. Organizations such as the Building Seismic Safety Council (BSSC), the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), the American Institute of Architects (AIA), the American Society of Civil Engineers (ASCE), the Applied Technology Council (ATC), the Earthquake Engineering Research Institute (EERI), and many state and regional structural engineers associations have developed material standards, testing procedures, and design parameters. Beyond this, the major manufacturers of almost every component used in buildings (such as roofs and windows) are members of a trade association that develops standards and design guidelines. This information often is incorporated directly into model codes or serves as background assistance for design and construction professionals.

CODE CHANGE PROCEDURES

A brief outline of some aspects of the code evolution and change process of the model code organizations is presented below as an overview of the general way in which states, counties, and cities develop regulations. Each of the model code groups publishes a new edition every three years and issues amendment supplements each year.

MODEL CODE CHANGE PROCEDURES

Each of the model code groups operates on an annual change cycle so that a code change can be fully processed within a 12-month period.

Each model code group distributes to its membership and all other interested parties a booklet of proposed code changes and a booklet of recommendations by the organization's code revision committee. Each code change proposal is identified with a specific number so that it can be tracked through the code change process. Although anyone may submit a code change proposal to a model code group, those doing so are encouraged to submit adequate substantiating material so that the code revision committees can base their recommendations on factual information.

The model code organizations' code revision committees generally are composed of the organizations' voting members (usually individuals representing a code enforcement entity such as a city, county, or state). Ad hoc committees for each of the model code organization are appointed to study special topics and are composed of all interested parties with appointments limited when required to maintain a balance of interests. All model code hearings are open to the public, and any individual or organization may present testimony on any agenda item. Some entities such as national trade associations, professional associations or committees appointed by the model code group can exert special influence on the code change process and it is up to each code revision committee as a whole to maintain balance.

A committee recommendation is made on each code change proposal. This recommendation may be for approval as submitted, approval as revised at the hearing, or disapproval. In some instances, further study may be recommended.

Committee actions, with reasons for each recommendation, are published and distributed to the model code membership and other interested parties. These actions become the agenda base for a public hearing and membership vote during the model code groups' annual meetings. Final action taken by voting members at an annual meeting (or, in some cases, by letter ballot) are published either in the form of annual supplements and/or as part of the triennial code editions.

STATE CODE ADOPTION PROCEDURES

The adoption of building regulations by states may take a variety of forms. The two most common are total pre-emption, in which the state develops or adopts rules and regulations that must be enforced by the local jurisdiction, or partial pre-emption, in which the state regulations are minimum standards and the local jurisdiction may adopt equal or more restrictive regulations.

In states that have mandatory statewide building regulation (currently approximately 25 states have some form of building regulation), proposed new rules usually are submitted as amendments to existing regulations. When the proposed rules are included in a model code forming the basis of the state code, they may be adopted very simply as a routine update to the model code on an annual basis or upon publication of a new edition of the model code.

In states that do not regulate building, an initiative must be generated by one or more interested persons who arrange for a member of the legislature to introduce a bill containing the proposed rules. Following introduction, the bill is assigned to one or more committees and placed on a calendar that directs its path through the legislative process. If it makes it through the process, the bill is signed by the governor and published in the statute books with responsibility for implementation placed in one of the state agencies.

LOCAL CODE ADOPTION PROCESS

When a city or county uses one of the model codes, new regulations are most readily introduced as part of that code's periodic revision and adoption process. In this situation, local opposition to the proposed rules may be significantly reduced since the public debate over the appropriateness of the rules already has been conducted at the national level; thus, any local opponent must show that the local community's uniqueness warrants noncompliance with the national standards.

When a locally written code is in effect or there is no code at all, new rules must have a local sponsor such as a councilman, building official, fire official, or legal counsel to initiate preparation of an adoption ordinance. Once introduced, a proposed ordinance usually is assigned to a local government standing committee or subcommittee for presentation and discussion at public hearings, the results of which will influence, to a great extent, whether the committee or subcommittee recommends that the ordinance be passed, be referred back for amendment, or be defeated.

Once adopted and after publication in an official paper, an ordinance usually becomes effective on a date specified in the ordinance or set forth by statute and is assigned an agency or department, usually the city or county building department, for implementation and enforcement. The building official then needs to review, and revise as necessary, his rules of procedure to reflect the newly adopted ordinance. Plan review, permit, and inspection procedures must be evaluated for adjustment. Personnel training and qualification in the plan review, permit, and inspection procedures also must be reviewed and updated as necessary.

Appendix C

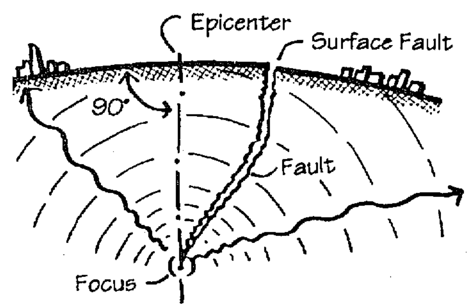
EARTHQUAKES, BUILDINGS, AND THE *NEHRP RECOMMENDED PROVISIONS*

The information that follows in this appendix has been excerpted from another book prepared for FEMA by the BSSC, *A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions* (FEMA Publication 99). Those readers who find this appendix of interest and would like to learn more about how the *Provisions* treats seismic design are encouraged to order this free document from the BSSC.

THE NATURE OF EARTHQUAKE GROUND MOTION

The Origin of Earthquakes

Most earthquakes are the result of abrupt slippage along a fault zone below the surface of the earth. This slippage eventually may result in "*surface faulting*," the cracking or breaking apart on the earth's surface that typifies movie visions of earthquakes.

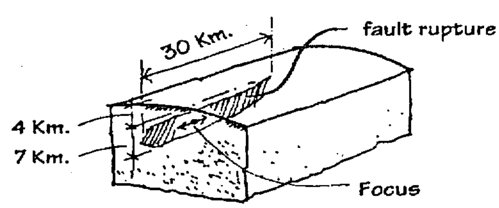


The point where the first slip on the fault occurs is called the "*focus*" or "*hypocenter*." The "*epicenter*" is a theoretical point on the earth's surface that is vertically above the focus. The earthquake starts at the focus, not the epicenter.

Faults and Waves

There are several kinds of faults but, for seismic design purposes, the concern is not what kind of fault slippage generated when the fault slips occurs, but rather what will be the nature of the ground motion to which the building will be subjected.

There is often extensive surface faulting in large earthquakes in the immediate vicinity of the fault. In the 1906 California earthquake, the fault broke the surface over a distance of over 200 miles with lateral movement of as much as 20 feet. In the 1992 Landers earthquake, east of Los Angeles, the fault broke the surface over a distance of 48 miles with lateral movements of up to 18 feet reported.



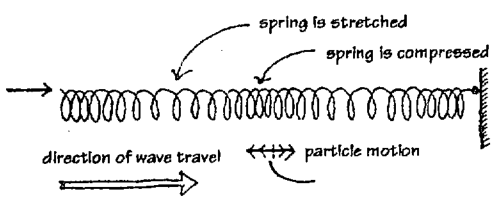
LOMA PRIETA FAULT RUPTURE

When such a large movement occurs, a building straddling the fault would be severely damaged since no building can be designed to deal with such large ruptures. However, this kind of disturbance of the ground is generally quite narrow in width to either side of the fault (in Landers, the maximum width of severely disturbed ground was about 125 feet. Beyond this area, structures are affected only by general ground shaking, and this is what seismic design is intended to deal with. Since almost all building damage is caused by ground motion rather than by fault rupture, this strategy makes sense.

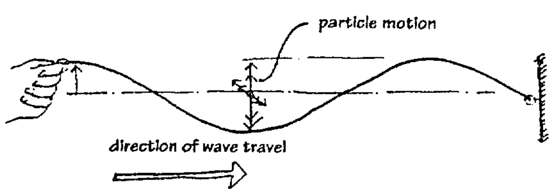
Once the fault slips, the rupture spreads rapidly along the fault. The rupture creates waves of vibration deep in the earth that spread in all directions from the point of inception and along the fault. The seismic waves begin like ripples in a still pond when a pebble is thrown into it, but they rapidly become much more complex.

Because the waves spread not only from the focus but also along the length of the fault rupture as it spreads rapidly along the fault, the intensity of the ground shaking has *directivity* – that is, the waves of vibration are of greater magnitude and last longer in the direction of fault rupture. In addition, the heavy shaking tends to reduce more rapidly in the direction normal to the fault line so that the area of heavy shaking has an elongated shape when viewed from above, instead of being a circle that is centered on the focus.

Studies of recent large earthquakes, such as Landers, Northridge and Kobe, also have shown that a few large pulses of long-period energy often occur towards the beginning of the earthquake close to the fault line. Because of the directivity effect, these large pulses can cause severe and almost instantaneous damage to relatively large, long-period buildings and structures such as bridges that are located close to and along the line of the fault.



P WAVE



S WAVE

There are four main types of seismic waves: two "body" waves within the earth and two "surface" waves confined to the surface layers of the earth. All four are considered in design. First to arrive at the surface is the *P* or *primary* wave. In this wave, the ground is successively pushed and pulled along the wave front. The motion of the ground is analogous to that of a coil spring when one end of the spring is moved. Successive waves can be created that move along the spring from one end to the other, alternately stretching and compressing the coils. A point on a coil – analogous to a spot on the ground – will announce the arrival of the wave by an abrupt movement in the direction of the wave and then will move only back and forth.

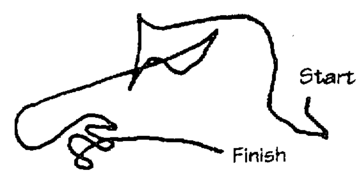
The *P* wave is followed by the *S* or *secondary* or *shear* wave, which is a motion at right angles to the wave front. This can be represented by pulling one end of a horizontal rope rapidly up and down to create waves that travel the length of the rope. A point on the rope will move only perpendicular to the direction of the rope which, for the ground, represents both lateral and vertical motion. When the wave reaches the surface, the motion is mostly horizontal. Just as the *P* wave travels faster than the *S* wave, the back and forth motion of a particle in the *P* wave is faster than the sideways motion of a particle in the *S* wave.

The *P* wave produces a jolt followed soon after by the "rolling" motion of the *S* wave. The two other waves are only at the earth's surface; the *Rayleigh* wave is an elliptical wave in the vertical plane and the *Love* wave is a surface wave that produces sideways motion similar to that of the *S* wave.

These different waves can be identified on records generated by modern strong-motion instruments and an observer some distance from the epicenter often can feel the difference between the "punch" of the primary wave and the "roll" of the secondary wave.

Within a few seconds, all the waves participate and the result is a random wave motion, predominantly in all horizonal directions but also somewhat vertical. The actual ground movement (and consequent building motion) is small, even in a major earthquake, except in the immediate vicinity of a fault rupture. The problem for a building is that the result is hundreds or thousands of tons of steel, concrete, and other materials moving back and forth a few inches in a very violent manner.

Although study of building damage after earthquakes generally shows a clear direction to the shaking (buildings will suffer varying damage depending on the orientation of their long or short sides), this seismic direction cannot be anticipated and therefore does not influence design.

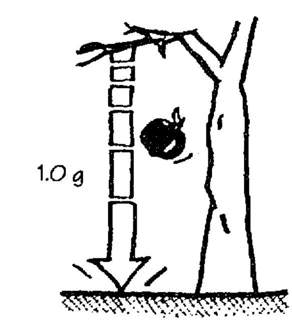


Scratch left on the floor by a kitchen range in the 1933 Long Beach, California earthquake.

Although seismic waves create ground motion that is predominately horizontal, there also often is considerable vertical motion. However, all buildings are designed to withstand vertical loads – the weight of the building and its contents – and large safety factors are used (that is, the calculated loads are multiplied by 2 or 3 to determine the loads for which the building is designed). These large safety factors mean that vertical earthquake forces are generally not a problem, but there are rare cases in which the vertical seismic forces exceed gravity, and buildings and other objects may be tossed into the air. Such was the case in the 1971 San Fernando earthquake when a fireman was tossed out of bed onto the floor and his bed fell on him. Large vertical accelerations in the Northridge earthquake also are believed to be responsible for some of the damage. In spite of these instances, however, seismic design and seismic codes focus on providing resistance to the horizontal forces that try to abruptly push buildings and objects sideways in all directions.

Forces and Gravity

The seismic body and surface waves create inertial forces within the building. These are the forces that may cause damage and are what seismic design tries to cope with. Inertial forces are created within an object when an outside force tries to make it move if it is at rest or change its rate or direction of motion if it is already moving. Inertial force takes us back to high school physics and to *Newton's Second Law of Motion* for when a building shakes it is in motion and must obey this law just as if it were a plane, a ship, or an athlete. Newton's Second Law of Motion states, in essence, that an *inertial force, F, equals mass, M, multiplied by the acceleration, A.*



32 ft. per sec^2

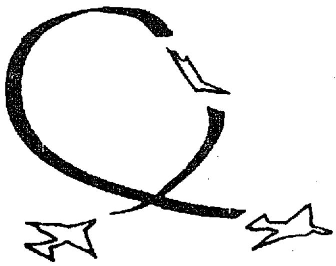
ONE "G" (NEWTON'S APPLE)

Mass can be taken as equivalent (at ground level) to the weight of the building and so this part of the law explains why light buildings, such as wood frame houses, tend to perform better in earthquakes than large heavy ones – the forces on the structure are less.

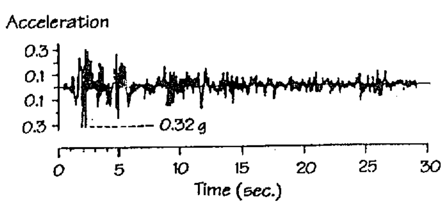
The acceleration or the rate of change of the velocity of the waves setting the building in motion determines the percentage of the building mass or weight that must be dealt with as a horizontal force. Acceleration is measured in terms of *the acceleration due to gravity* or "g." One "g" is the rate of change of velocity of a free-falling body in space . This is an additive velocity of 32 feet per second per second. Thus, at the end of the first second, the velocity is 32 feet per second; a second later it is 64 feet per second; and so on. When parachutists or bungee jumpers are in free fall, they are experiencing an acceleration of 1 "g." A building in an earthquake experiences a fraction of a second of "g" forces in one direction before they abruptly change direction.

FORCE = MASS x ACCELERATION

Engineering creations (planes, ships, cars, etc.) that are designed for this dynamic or moving environment can accommodate very large accelerations. Military jet planes, for example, are designed for accelerations of up to 9 "g." At this acceleration, the pilot experiences 9 times his body weight pressing down on his organs and blacks out. A commercial airliner in fairly severe turbulence may experience about 20 percent "g" (or 0.2g) as may a fast moving train on a rough track.



Military Jet - 9 g



ACCELERATION

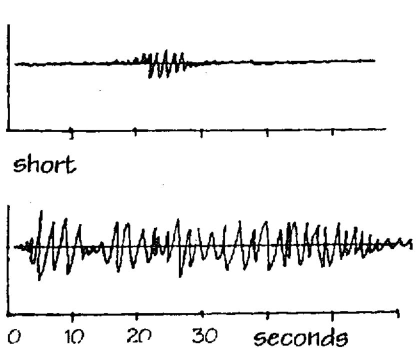
Poorly constructed buildings begin to suffer damage at about 10 percent "g" (or 0.1g). In a moderate earthquake, the waves of vibration may last for a few seconds, and accelerations may be approximately 20 percent "g." For people on the ground or at the bottom of a building, the sensations will be very similar to those of the occupants of a plane in turbulence or passengers in the corridor of a fast moving train over a somewhat uneven track: they feel a little unsteady and may need to grab on to something to help them remain standing. In large earthquakes, the heavy shaking will last for more than a few seconds but, except for rare major events, will not reach one minute. Sustained accelerations may, for a fraction of a second, be as high as 0.6 or 0.7 "g." Acceleration "spikes" – single very short duration accelerations – that reach almost 2 "g" have been recorded by instruments but these are so rapid that they do not damage the building and are not sensed by people.

ACCELERATION "SPIKE"

Duration, Velocity, and Displacement

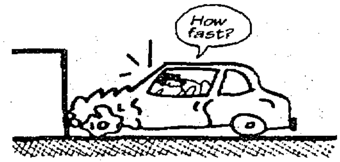
Because of the inertial force formula, acceleration is a key factor in determining the forces on a building, but other characteristics of the earthquake waves also are important.

One of these has already been mentioned. This is *duration* – how long the heavy shaking lasts. Although those who have experienced bad earthquakes believe the shaking lasts a lifetime, in fact almost all significant earthquake shaking can be measured in a few seconds. Duration is important because continued shaking weakens a building structure and reduces its resistance to earthquake damage.



DURATION

Two other measures are directly related to acceleration and can be mathematically derived from it. *Velocity,* which is measured in inches per second or centimeters per second, refers to the rate of motion at any given instant. For example, when a moving car hits an obstacle, it suddenly decelerates and, if the car occupants are not belted in and there are no airbags, they lurch forward toward the windshield. How fast, at that instant, are the occupants moving? The abrupt stop determines the extent of occupant injury and also affects the extent of damage to a structure.



VELOCITY

Displacement, measured in inches or centimeters, refers to the distance a point on the ground is moved from its initial location. Points in a building affected by shaking also will be moved to a comparable, or greater, extent so that this affects the structure (and also the comfort and security of the building occupants).

Acceleration, velocity, and displacement are mathematically and physically related and can be derived from one another.

CRITICAL BUILDING CHARACTERISTICS

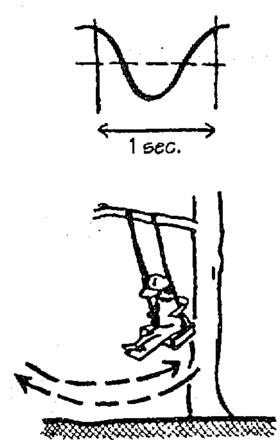
So far, we have been describing the *input motion* – the characteristics of ground motion that affect the building. However, there also are some important things about a building itself that, *in conjunction with* the ground motion, affect its performance and may dictate whether it collapses or survives.

Period and Amplification

Another very important characteristic of earthquake waves is their period or frequency – that is, whether the waves are quick and abrupt or slow and rolling. This phenomenon is particularly important for determining building seismic forces.

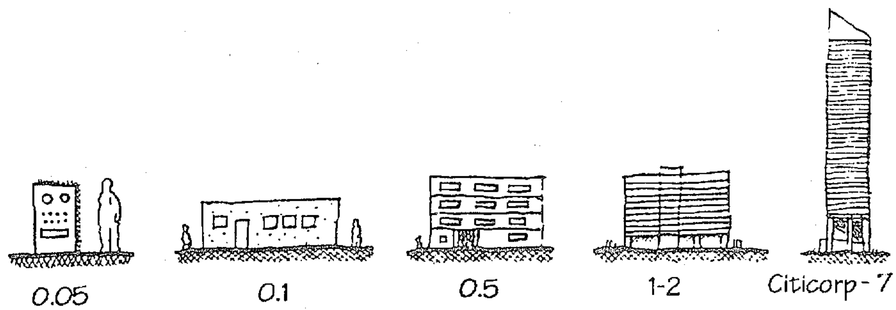
All objects have a *natural or fundamental* period; this is the rate at which they will move back and forth if they are given a horizontal push. In fact, without dragging it back and forth, it is not possible to make an object vibrate at anything other than its natural period. When a child in a swing is started with a push, to be effective this shove must be as close as possible to the natural period of the swing. If correctly gauged, a very small push will set the swing going nicely. Similarly, when earthquake motion starts a building vibrating, it will tend to sway back and forth at its natural period.

When a vibrating structure is given further pushes that are also at its natural period, the structure tends to *resonate*. Its vibrations increase dramatically in response to even rather small pushes and, in fact, its accelerations may increase as much as four or five times.



NATURAL, or FUNDAMENTAL PERIOD

Natural periods vary from about *0.05 seconds* for a piece of equipment such as a filing cabinet to about *0.1 seconds* for a one-story building. Period is the inverse of frequency so the cabinet will

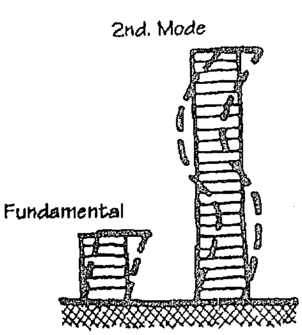


FUNDAMENTAL PERIODS

vibrate at 1/0.05 = 20 cycles a second or 20 Hertz. A four-story building will sway at about a *0.5 second* period and taller buildings between about 10 and 20 stories will swing at periods of about *1 to 2 seconds*. A rule of thumb is that the building period equals the number of stories divided by 10; therefore, period is primarily a function of building height. The 60-story Citicorp building in New York has a period of *7 seconds;* give it a push and it will sway slowly back and forth completing a cycle every 7 seconds. Other factors such as the building's construction materials, which affect the stiffness of the structure, and the building's geometric proportions also affect the period, but height is the most important consideration.

Taller buildings also will undergo several *modes of vibration* so that the building will wiggle back and forth like a snake. For seismic purposes, however, the natural period generally is the most significant.

The ground, of course, also vibrates at its natural period. The natural period of ground in the United States varies from about *0.4 seconds* to *2 seconds* depending generally on the hardness of the ground. Very soft ground may have a period of up to *2 seconds* since it cannot sustain longer period motions except under certain unusual conditions. Since this range is well within the range of common building periods, it is quite possible that the pushes that the ground gives the building will be at the natural period of the building. This may create *resonance*, causing the structure to have to deal with accelerations of perhaps *1 "g"* when the ground is only vibrating with accelerations of *0.2 "g."*

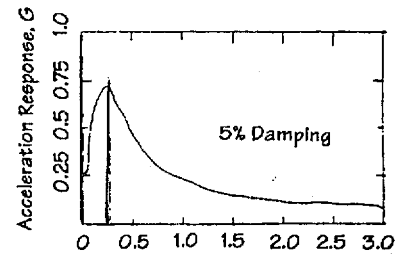


MODES OF VIBRATION

The terrible destruction in Mexico City in the earthquake of 1985 was primarily the result of response amplification caused by coincidence of building and ground motion periods. Mexico City was some 250 miles from the earthquake focus, and the earthquake caused the soft ground under the downtown buildings to vibrate for over 90 seconds at its long natural period of around 2 seconds. This caused tall buildings between about 10 and 20 stories to resonate at a similar period, greatly increasing the accelerations within them. This amplification in building vibration is very undesirable. The possibility of it happening can be reduced by trying to ensure that the building period will not coincide with that of the ground. Thus, on soft (long period) ground, it would be best to design a short stiff (short period) building.

There is also a more general amplification effect related to different types of ground. Earthquake ground shaking tends to be greater on soft ground than on hard ground such as rock. As a result, earthquake damage tends to be more severe in areas of soft ground. This characteristic became very clear when the 1906 San Francisco earthquake was studied and maps were drawn that showed building damage in relation to the ground conditions. Studies after the 1989 Loma Prieta earthquake also showed that shaking in the soft ground around San Francisco Bay was two and a half to three and a half times that of shaking in rock. Extensive damage was caused to buildings in San Francisco's Marina district, which was largely built on filled ground, some of it rubble deposited after the 1906 earthquake.

To assist the engineer in determining whether there may be a problem because the period of a new building is close to that of the site, curves for the site can be drawn (based on information about the nature of the ground) that show estimates of the periods at which *maximum building response* is likely – that is, the building periods for which maximum shaking can be anticipated. Such a curve is termed the *site response spectrum*. This spectrum shows the accelerations (on the vertical ordinate) that may be expected at varying periods (the horizontal ordinate). Thus, the response spectrum illustrated shows a maximum response at a period of about 0.3 seconds – the fundamental period of a mid-rise building. Based on this knowledge, the building design might be adjusted to ensure that the building period does not coincide with the site period of maximum response. For the figure shown, with a maximum response at about 0.3 seconds, it would be appropriate to design a building with a longer period of 1 second or more. Of course, it is not always possible to do this, but the response spectrum shows clearly what the possible accelerations at different periods are likely to be and the building can then be designed accordingly.



TYPICAL SITE RESPONSE SPECTRUM

Damping

The important relationship between the building and ground motion periods was illustrated in above using a the child's swing to show how the swinging motion is amplified by an *input motion*, in this case a judicious push. However, the child's swing is a pendulum that vibrates very efficiently and continue to swing for many minutes after any assistance even though the amplitude will diminish. Buildings and other objects do not swing as efficiently as pendulums because the vibration is *damped* or reduced. The extent of damping in a building depends on the materials of construction, how those materials are connected together, and on its architectural elements such as partitions, ceilings, and exterior walls.

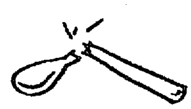
Higher Forces and Uncalculated Resistance

Even if a building is well damped and will not resonate, it may be subjected to forces that are much higher than the computed forces for which it was designed. Why is this the case? Because designing a building for the rare maximum conceivable earthquake forces and then adding a factor of safety of two or three times as is done for vertical loads would result in a very expensive structure whose functional use would be impeded by huge walls and columns.

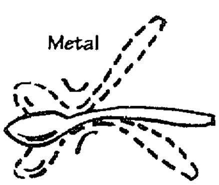
Experience shows, however, that many buildings have encountered forces far higher than they were designed to resist and yet have survived, sometimes with little damage. This phenomenon can be explained by the fact that the analysis of forces is not precise and deliberately errs on the conservative side so that the building can really survive higher forces than is apparent. In addition, the building often gains additional strength from components, such as partitions, that are not considered in an analysis. Some structural members may be sized for adequate stiffness rather than for strength. Finally, materials often are stronger in reality than the engineer assumes in his calculations. Taken together, these factors provide a considerable safety factor or uncalculated additional resistance.

Ductility

An additional property of materials is used to ensure that a building may adequately resist much more than its design ground shaking. This material property is called *ductility*. Ductility is the characteristic of certain materials – steel in particular – to fail only after considerable distortion or deformation has occurred. This is why it is much more difficult to break a metal spoon by bending it than one made of plastic. The metal object will remain intact – though distorted – after successive bending to and fro while the plastic spoon will snap suddenly after a few bends. The metal is far more *ductile* than the plastic.



BRITTLENESS



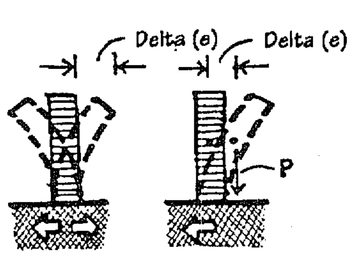
DUCTILITY

The deformation of the metal (even in the spoon) absorbs energy and defers absolute failure of the structure. The material bends but does not break and so continues to resist forces and support loads, although with diminished effectiveness. The effect of earthquake motion on a building is rather like that of bending a spoon rapidly back and forth – the heavy structure is pushed back and forth in a similar way several times a second (depending on its period of vibration).

Brittle materials, such as unreinforced brickwork or unreinforced concrete, fail suddenly with a minimum of distortion. However, the steel contained in a well designed modern reinforced concrete structure can give the combined material the ductility that is needed for earthquake resistance.

Thus, buildings are designed in such a way that in the rare case when they are subjected to forces higher than those required by a code, the materials and connections will distort but not break. In so doing, they will safely absorb the energy of the earthquake vibrations, and the building, although distorted and possibly unusable, is at least still standing.

Overturning



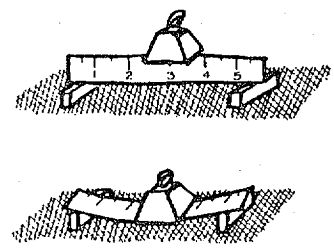
P-DELTA

Although building mass or weight was discussed as part of the *F = MA* equation for determining the horizontal forces, there is another way in which the building's weight may act under earthquake forces to overload the building and cause damage or even collapse.

Vertical members such as columns or walls may fail by *buckling* when the mass of the building exerts its gravity force on a member distorted or moved out of plumb by the lateral forces. This phenomenon is known by engineers as the *P-e or P-delta* effect, where *P* is the gravity force or weight and e or delta is the eccentricity or the extent to which the force is offset. All objects that overturn do so as a result of this phenomenon.

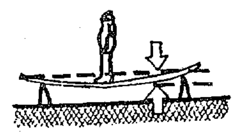
The geometrical proportions of the building also may have a great influence on whether the *P-delta* effect will pose a problem since a tall slender building is much more likely to be subject to overturning forces than a low squat one. However, in earthquakes, buildings seldom overturn. This is because structures are not homogeneous but are composed of many elements connected together; the earthquake forces will pull the components apart and the building will fall *down*, not over. Strong, homogeneous structures such as filing cabinets, however, will fall over.

Strength, Stiffness, and Drift



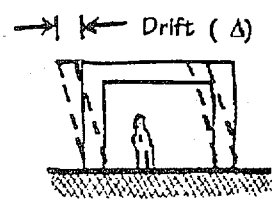
STIFFNESS, STRENGTH

Two important related characteristics of any structure are its *strength* and its *stiffness*. Two structural beams may be equally strong (or safe) in supporting a load but may vary in their stiffness – the extent to which they bend or *deflect* in doing so. Stiffness is a material property but it also is dependent on *shape*. This concept can be easily understood by visualizing the flexibility of a long ruler placed where it has to support a load; how well it supports the load will depend on whether the load is placed on the ruler's flat surface or on its edge.



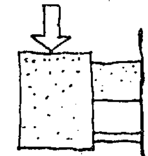
DEFLECTION

The measure of stiffness is *deflection*, the extent to which a structural element moves or bends when loaded. For vertical gravity loads, this is usually the only aspect of stiffness that is of concern. When floor joists are designed for a house, for example, it is often deflection rather than strength that dictates the size of the joists – that is, the depth of the joists is determined by how much they will bend under load rather than by whether they can safely support the floor loads. Typically, an unacceptable amount of bending will occur well before the joists are stressed to the point at which they may break because of the loads. (Stress refers to the internal forces within a material or member. The stress is created as the structural member resists the applied load. Stress is expressed in force per unit area – for example, pounds per square inch. Codes provide stress limits that are not to be exceeded for commonly used materials.)

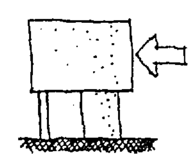


DRIFT

The analogous lateral force condition occurs when limitations on *drift*, the horizontal story-to-story deflection, impose more severe requirements on members than the strength requirements. Drift limits serve to prevent possible damage to interior or exterior walls that are attached to the structure and which might be cracked or distorted if the structure deflects too much laterally. The strength issue involves using a material strong enough to resist a load without exceeding a safe stress in the material while the drift issue involves preventing a structure from moving out of vertical alignment more than a given amount.

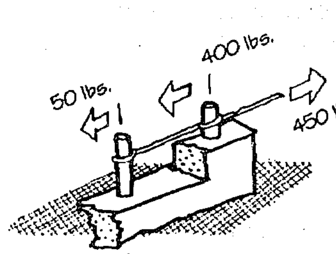


Vertical

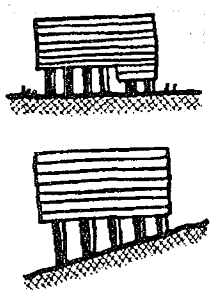


Horizontal

In seismic design, there is another very important aspect to stiffness. The problem of determining the overall lateral force on the building by multiplying the building weight by its acceleration has already been discussed. But how is this force distributed among the various elements of a building? The engineer needs to know this so that each member and connection can be properly designed to withstand the forces it may encounter. *Relative stiffness* enters into this issue because the applied forces are "attracted to" and concentrated at the stiffer elements of the building – in engineering terms, the forces are *distributed in proportion to the stiffness of the resisting elements.*



Why this is so can be understood by visualizing a heavy block supported away from a wall by two short beams. Clearly, the thick, stiff beam will carry much more load than the slender one, and the same is true if they are turned 90 degrees to simulate the lateral force situation.



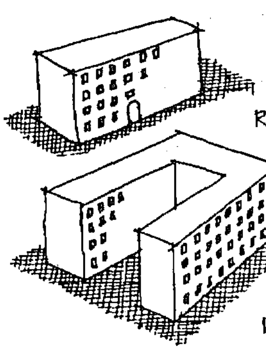
SHORT COLUMNS

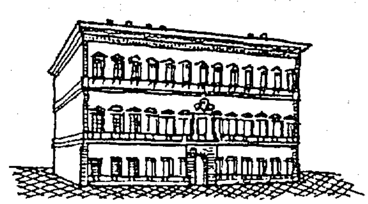
An important aspect of this for column lateral stiffness is illustrated in the next sketch. Mathematically, the stiffness of a column approximately varies as the cube of its length. In this diagram, the columns have the same cross-section but the short column is half the length of the long one. Therefore, the short column will be *eight* times stiffer (2^3) instead of *twice* as stiff and will take *eight times the horizontal load* of the long column. This concept has serious implications for buildings with columns of different lengths, and in designing a building, the engineer tries to equalize the stiffness of the resisting elements so that no one member or small group of members takes a disproportionate amount of the load. If this cannot be done (for architectural reasons, for example), then the designer must make sure that stiffer members are appropriately designed to carry their proportion of the load.

Building Size and Shape

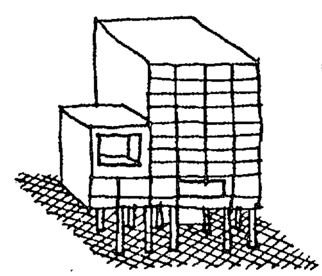
The size, shape, and geometrical proportions of a building are termed its *configuration*. How the building configuration relates to its structural systems has a major influence on the building's ability to withstand shaking.

Many years ago when engineers first started studying the earthquake problem in a systematic way, they noticed that buildings with certain shapes and proportions seemed to be more prone to damage in earthquakes than others no matter what construction materials or structural systems had been used. In general, the more *irregular* the building – that is, the more the building deviated from a regular simple symmetrical shape – the more likely it seemed to suffer damage.





Decorated box

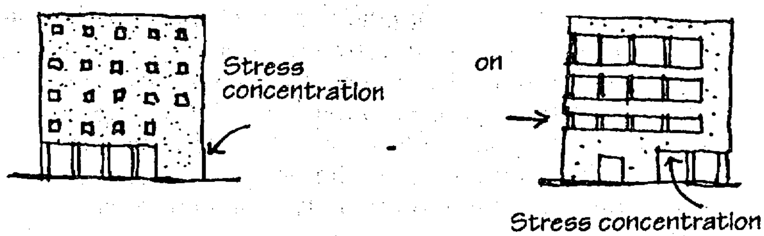


Modern structure

In the past, buildings tended to have simple configurations because traditional materials such as stone and brick did not allow for much more than superficial or surface decorative irregularity in design. (Sometimes, as in a medieval Gothic cathedral or a Renaissance Italian palace, this surface "irregularity" achieved the highest and most enduring form of art.) But starting in the late nineteenth century, modern steel and reinforced concrete frame construction allowed for increased structural daring and permitted architects to conceive designs that would have been impossible with traditional masonry. Configuration irregularity results in two main effects – stress concentrations and torsional forces.

Stress Concentrations

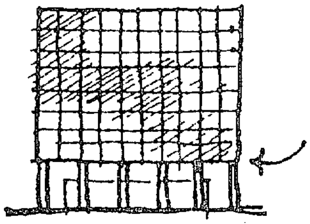
Irregularities tend to create abrupt changes in strength or stiffness that may concentrate forces in an undesirable way. These can be very difficult to deal with even in a modern structure. So, although the size of the overall force that the building must withstand is determined by the $F = MA$ equation, the way in which this is *distributed and concentrated* is determined by the configuration.



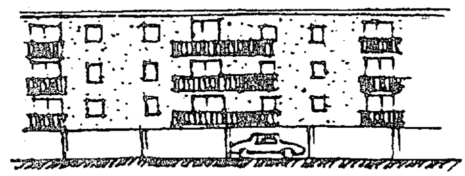
Stress concentration means that an undue proportion of the overall forces is concentrated at one or a few points of the building such as a particular set of beams, columns, or walls. These few members may fail and, by a chain reaction, bring down the whole building. Because, as has been noted, forces are attracted to the stiffer elements of the building, these also tend to be locations of stress concentration. People who are in the building demolition business know that if they weaken a few key columns or connections in a building, they can bring it down. An earthquake also tends to "find" these "weak links."

Stress concentration can also be created by vertical irregularity. The most serious condition of vertical irregularity is that of the *soft*, or weak, story in which one story, usually the first, is significantly weaker or more flexible than those above. A high first story is often architecturally desirable to accommodate larger rooms – lobbies, banking floors, or hotel meeting rooms. The design creates a major stress concentration at the points of discontinuity and, in extreme circumstance, may lead to collapse unless adequate design is provided at such points. A common example of the soft first story occurs in apartment houses, which often allocate all or most of the first floor to parking, with widely spaced columns and a minimum of walls.

The first floor of the Northridge Meadows apartments, designed before the problem of the soft first story was fully understood, collapsed in the 1994 Northridge earthquake, with considerable loss of life. Many other similar apartments also collapsed or were severely damaged, but fortunately only automobiles were destroyed.



Soft story

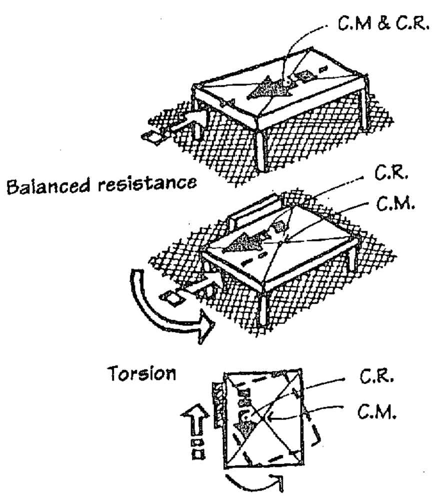


NORTHRIDGE MEADOWS APARTMENTS

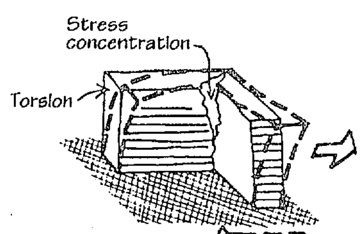
Torsional Forces

In addition to stress concentrations, irregularities, particularly in plan, may permit what are called *torsional* or twisting forces to develop, which contributes a significant element of uncertainty to an analysis of building resistance. ("Plan" refers to the horizontal layout of the building which may be a simple square or rectangular or an irregular shape with wings of different shapes and proportions.)

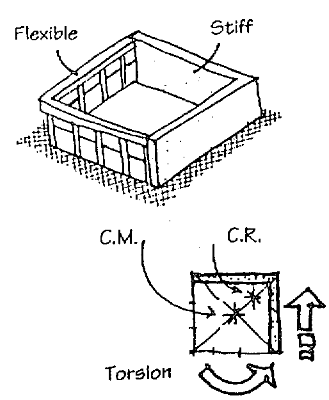
Torsional forces are created in a building by a lack of balance between the location of the resisting elements and the arrangement of the building mass. Engineers refer to this as *eccentricity* between the *center of mass* and the *center of resistance*, which tends to make the building rotate around the latter and creates torsion in the resisting elements. In a building, the main lateral force is contributed by the weight of the floors, walls, and roof, and this force is exerted through the center of mass, usually the geometric center of the floor (in plan). If the resistance provided by walls and columns pushes back through this point (the center of resistance), then there is no torsion and balance is maintained. If not, torsion is introduced and dangerous concentrations of stress can be created. This is the reason why it is recommended that buildings in areas of seismic risk be designed to be as symmetrical as possible.



TORSION



L-SHAPED BUILDING



PERIMETER VARIATION

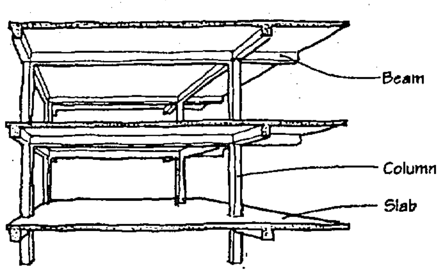
One building configuration that is most likely to produce torsion features *re-entrant corners* (buildings shaped like an L or a T for example). The wings of such buildings tend to twist and produce torsional forces. In addition, re-entrant corner buildings also tend to produce *stress concentration* at the "notch" where the wings meet because this location often is stiffer and therefore attracts a higher proportion of the forces.

Buildings that have large *variations in their perimeter resistance* on different sides of the building also tend to produce torsion. This form of variation in perimeter resistance occurs often in buildings such as stores in which side and end walls may be masonry or concrete party walls while the front wall may be largely glass. The centers of mass and resistance do not balance and, in extreme cases, the building can tear itself apart.

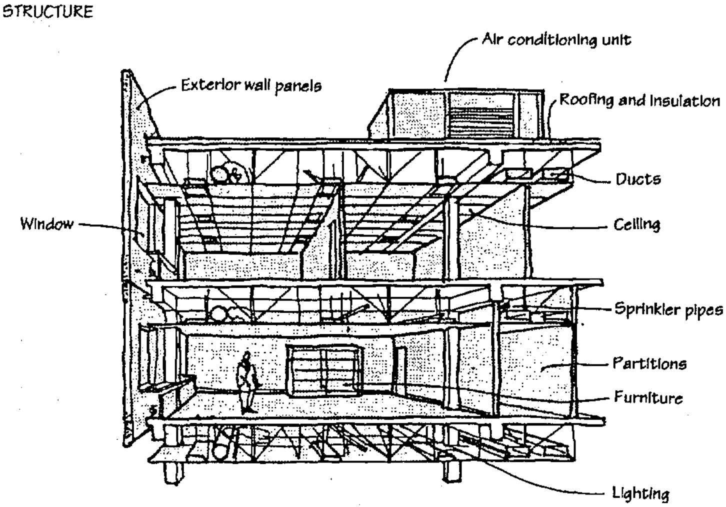
Nonstructural Components

For a long time, seismic building codes focused exclusively on the *structure* of the building – that is, the system of columns, beams, walls and diaphragms that provides resistance against earthquake forces. Although this focus remains dominant for obvious reasons, experience in more recent earthquakes has shown that damage to *nonstructural components* is also of great concern. In most modern buildings, the nonstructural components account for 60 to 80 percent of the value of the building.

Nonstructural components surround us at work or at home – ceilings, partitions, light fixtures, windows, and exterior walls. They are also the components that enable the building to function – the power, heating, cooling, and elevator systems and, for buildings like hospitals, the medical equipment that maintains or saves lives. Damage to nonstructural components



STRUCTURE



NONSTRUCTURE (shaded)

can result in great economic loss, in terms of both the cost of repair and the loss of building use and business interruption while the building is closed for repair. If the building is a critical facility such as a hospital, damage to utility systems providing such things as water and power may shut the building down when it is most needed.

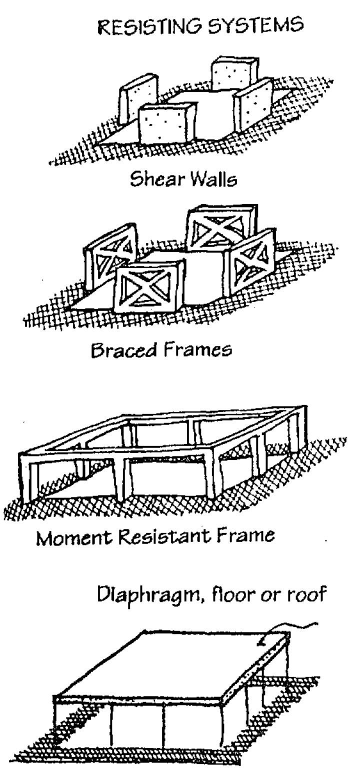
Nonstructural damage often is caused by movement of the building structure that is perfectly acceptable as far as the safety and stability of the structure is concerned. But the nonstructural components and finishes that are rigidly attached to the structure are bent and twisted in way that they cannot accommodate with the result that tiles fall off walls and plaster partitions and ceilings crack. This kind of damage is hazardous to occupants and can be difficult and expensive to repair.

Construction Quality

One other characteristic that applies to any building must be mentioned: it must be constructed well if it is to perform well. The materials from which it is constructed must have the necessary basic strength and expected properties. Most important, all the building's components must be securely connected together so that as they push and pull against one another during the earthquake, the connections are strong enough to transfer the earthquake forces and thereby maintain the integrity of the structure.

Framing Systems

How does an engineer design a building to resist all the forces that are produced by ground motion? Essentially, he must choose from a small set of components and then combine them in his design to form a complete resistance system.



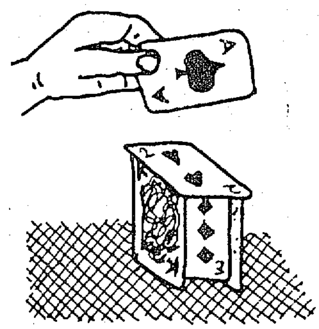
Three kinds of framing systems can resist the lateral forces generated in a building by an earthquake – *shear walls, braced frames*, and *moment resisting frames* (sometimes called rigid frames). These three types of framing system are really alternatives. Although designers sometimes mix components, using one type in one direction and another type in the other, this is inadvisable, mainly because the different systems have different stiffnesses and it is difficult to obtain balanced resistance when they are mixed.

Thus, the designer generally chooses only one type of framing system to resist the applied loads. This must be done at an early stage in the design because the different characteristics of these components have a considerable effect on the architectural design, both functionally and aesthetically. For example, if shear walls are chosen as the *seismic force resisting system*, the building will feature a pattern of permanent structural walls that run through every floor from roof to foundation. While this may be acceptable if the building is to be an apartment house or hotel, it will not work well if the building is to be a rental office building where internal space requirements will change regularly.

It should be noted that moment resistant frames sometimes are combined with one of the other systems to produce a *dual system*, in which the moment resistant frame backs up the other system. In this case, the two systems interact to share the load.

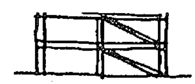
In the horizontal plane, *diaphragms,* generally formed by the floor and roof elements of the building, are necessary. (Sometimes, however, horizontal bracing systems independent of the roof or floor structure serve as diaphragms.) Diaphragms transfer the lateral forces to the vertical resistant elements – the shear walls or frames.

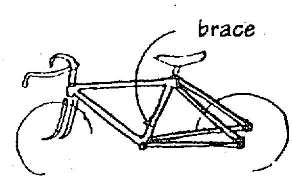
Shear walls are designed to receive lateral forces from diaphragms and transmit them to the ground. The forces in these walls are predominantly shear forces in which the material fibers within the wall try to slide past one another. A card house is a shear wall structure, and sufficient "card" walls must be placed at right angles to one another or the house will collapse. It is a very inefficient structure because the connections between the walls and between the walls and the diaphragms are nonexistent. If the walls are connected by slots or by tape, the structure is transformed into one that is very efficient for its size and weight. Similarly, the connections between the walls and floor and roof diaphragms in a building must be very strong and ductile.



Card House
- a shear wall structure

Braced frames act in the same way as shear walls; however, they generally provide less resistance but better ductility depending on their detailed design. Bracing provides lateral resistance through triangulated geometry, which prevents the frame from folding up if given a sideways push. A bicycle is a familiar example of a braced frame; without the connecting diagonal brace, the other members and connections would have to be much stronger to prevent the frame from folding up.

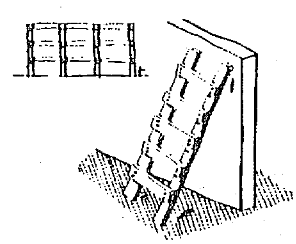




BRACED FRAME

In a building with a braced frame, lateral forces may cause the bracing to successively elongate and compress causing it to lose its effectiveness and experience large distortions that ultimately lead to collapse of the vertical structure it is trying to brace. Ductility therefore must be designed into the bracing so that it will deform but not snap.

A *moment resistant frame* is the engineering term for a frame structure in which the lateral forces are resisted primarily by bending in the beams and columns that is mobilized by strong rigid joints between columns and beams. (To engineers, a "moment" of a force about a point is the force multiplied by the distance between the point and the line of action of the force.) A simple ladder is an example of a moment resistant frame. In a building that uses a moment resistant frame, no walls or braced frames are required. The joints, however, become highly stressed and the details of their construction are very important in both steel and reinforced concrete.



MOMENT RESISTANT FRAME

As a last resort, moment resistant frames use the energy absorption obtained by ductility – that is, the permanent deformation of the structure prior to ultimate failure. For this reason, moment resistant frames generally are steel structures with bolted or welded joints in which the natural ductility of the material is an advantage. However, properly reinforced concrete frames that contain a large amount of precisely located steel reinforcing also are effective as ductile moment frames.

THE *NEHRP RECOMMENDED PROVISIONS*

This appendix has outlined the ways in which earthquake ground motion affects buildings and the ways in which building characteristics affect the response of buildings to this shaking. What the *Provisions* does is present procedures in the form of simple mathematical formulas and advisory precepts that the building designer uses as criteria for the building design. In doing this, the *Provisions* remains, however, focused the goal of providing a uniform level of safety for all building types in all areas of the United States even though there is great variability in the potential ground shaking hazard around the country.

As noted at the beginning of this appendix, readers interested in finding out more about the *Provisions* are encouraged to order FEMA Publication 99, *A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions*.

Appendix D

OVERVIEW OF U.S. SEISMICITY

INTRODUCTION

The U.S. Geological Survey (USGS), together with the National Science Foundation (NSF), conducts and sponsors the major national effort in earthquake-related studies in seismology, geology, and geophysics. At present, the USGS has identified nine geographic areas in the United States as priority study areas: the intermountain seismic belt including the Wasatch Front of Utah; Puget Sound, Washington; Alaska; southern California; Hawaii; the central Mississippi valley; the southeastern United States including Charleston, South Carolina; the northeastern United States including Massachusetts and New York; and Puerto Rico and the Virgin Islands. A considerable amount of data on the earthquake hazard in these areas is available from the USGS and ongoing studies are continually adding to the store of information. When integrated with geologic data, studies of seismicity provide answers to the questions *where*, *how big*, *how often*, and *why* earthquakes occur. The information on U.S. seismicity included here is based on ongoing research by the USGS National Earthquake Information Center. It is presented to alert the reader to the national nature of the seismic hazard. Detailed information about specific areas can be obtained from geologists, geophysicists, and seismologists affiliated with area academic institutions; regional offices of the USGS and FEMA; national earthquake information centers; and state and regional seismic safety organizations.

The Modified Mercalli intensity scale (MMI) is used in the seismicity information presented here as the reference when instrumental data to define Richter and surface wave magnitudes were unavailable. See Appendix A for a brief explanation of these terms.

NORTHEAST REGION

The record of earthquakes in the United States (and the Northeast) is believed to have started with the Rhode Island earthquake of 1568. Including earthquakes originating in the St. Lawrence River Valley in Canada, 16 important earthquakes have occurred in the northeast region since 1568.

Important Earthquakes of Eastern Canada and New England

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
1534-1535	St. Lawrence Valley	IX-X	
June 11, 1638	St. Lawrence Valley	IX	
Feb. 5, 1663	Charlevoix zone	X	7.0
Nov. 10, 1727	New Newbury, MA	VIII	7.0
Sept. 16, 1732	Near Montreal	VIII	
Nov. 18, 1755	Near Cape Ann, MA	VIII	
May 16, 1791	East Haddam, CT	VIII	
Oct. 5, 1817	Woburn, MA	VII-VIII	
Oct. 17, 1860	Charlevoix zone	VIII-IX	6.0
Oct. 20, 1870	Charlevoix zone	IX	6.5
Mar. 1, 1925	Charlevoix zone	IX	7.0
Aug. 12, 1929	Attica, NY	VIII	5.5
Nov. 18, 1929	Grand Banks of Newfoundland	X	8.0
Nov. 1, 1935	Timiskaming, Quebec	VIII	6.0
Sept. 5, 1944	Massena, NY; Cornwall, Ont.	VIII	6.0
Jan. 9, 1982	North Central New Brunswick	V	5.7 (m_b)

SOUTHEAST REGION

The southeastern United States is an area of diffuse, low-level seismicity. It has not experienced an earthquake having an MMI of VIII or greater in nearly 80 years. The largest and most destructive earthquake in the region was the 1886 Charleston earthquake which caused 60 deaths and widespread damage to buildings. It had an epicentral intensity of X and a magnitude (M_S) of approximately 7.7.

Important Earthquakes of the Southeast Region

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Feb. 21, 1774	Eastern VA	VII	
Feb. 10, 1874	McDowell County, NC	V-VII	
Dec. 22, 1875	Arvonia, VA area	VII	
Aug. 31, 1886	Near Charleston, SC	X	7.7
Oct. 22, 1886	Near Charleston, SC	VII	
May 31, 1897	Giles County, VA	VIII	6.3
Jan. 27, 1905	Gadsen, AL	VII-VIII	
June 12, 1912	Summerville, SC	VI-VII	
Jan. 1, 1913	Union County, SC	VII-VIII	5.7-6.3
Mar. 28, 1913	Near Knoxville, TN	VII	
Feb. 21, 1916	Near Asheville, TN	VI-VII	
Oct. 18, 1916	Northeastern AL	VII	
July 8, 1926	Mitchell County, NC	VI-VII	
Nov. 2, 1928	Western NC		

CENTRAL REGION

The seismicity of the central region is dominated by the four great earthquakes that occurred in 1811-1812 near New Madrid, Missouri. These earthquakes had magnitudes (M_S) ranging from 8.4 to 8.7 and epicentral intensities ranging from X to XII. Some 15 of the thousands of aftershocks that followed had magnitudes greater than 6.

Important Earthquakes of the Central Region Through 1980

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec. 16, 1811	New Madrid, MO	XI	8.6
Jan. 23, 1812	New Madrid, MO	X-XI	8.4
Feb. 7, 1812	Mew Madrid, MO	XI-XII	8.7
June 9, 1838	Southern IL	VIII	5.7
Jan. 5, 1843	Near Memphis, TN	VIII	6.0
Apr. 24, 1867	Near Manhattan, KS	VII	5.3
Oct. 22, 1882	West Texas	VII-VIII	5.5
Oct. 31, 1895	Near Charleston, MO	VIII-IX	6.2
Jan. 8, 1906	Near Manhattan, KS	VI-VIII	5.5
Mar. 9, 1937	Near Anna, OH	VIII	5.3
Nov. 9, 1968	Southern IL	VII	5.5
July 27, 1980	Near Sharpsburg, KY	VI	5.1

WESTERN MOUNTAIN REGION

A number of important earthquakes have occurred in the western mountain region. These include earthquakes in the Yellowstone Park-Hebgen Lake area in western Montana, in the vicinity of the Utah-Idaho border, and sporadically along the Wasatch front in Utah. The largest earthquake in the western mountain region in historic times was the 1959 Yellowstone Park-Hebgen Lake earthquake which had a magnitude (M_S) that is now believed to be in excess of 7.3. The strongest earthquake in 24 years occurred at Borah Peak in Idaho in October 1983; it had a magnitude of 7.3.

Important Earthquakes of the Western Mountain Region Through 1980

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Nov. 9, 1852	Near Ft. Yuma, AZ	VIII?	
Nov. 10, 1884	Utah-Idaho border	VIII	
Nov. 14, 1901	About 50 km east of Milford, UT	VIII	
Nov. 17, 1902	Pine Valley, UT	VIII	
July 16, 1906	Socorro, NM	VIII	
Sept. 24, 1910	Northeast AZ	VIII	
Aug. 18, 1912	Near Williams, AZ	VIII	
Sept. 29, 1921	Elsinore, UT	VIII	
Sept. 30, 1921	Elsinore, UT	VIII	
June 28, 1925	Near Helena, MT	VIII	6.7
March 12, 1934	Hansel Valley, UT	VIII	6.6
March 12, 1934	Hansel Valley, UT	VIII	6.0
Oct. 19, 1935	Near Helena, MT	VIII	6.2
Oct. 31, 1935 (Aftershock)	Near Helena, MT	VIII	6.0
Nov. 23, 1947	Southwest MT	VIII	
Aug. 18, 1959	West Yellowstone-Hegben Lake	X	7.1
Aug. 18, 1959 (Aftershock)	West Yellowstone-Hegben Lake	VI	6.5
Aug. 18, 1959 (Aftershock)	West Yellowstone-Hegben Lake	VI	6.0
Aug. 18, 1959	West Yellowstone-Hegben Lake	VI	6.5
Mar. 28, 1975	Pocatello Valley, ID	VIII	6.1
June 30, 1975	Yellowstone National Park	VIII	6.4
Oct. 28, 1983	Borah Peak, ID	VII est.	7.3

CALIFORNIA AND WESTERN NEVADA REGION

The highest rates of seismic energy release in the United States, exclusive of Alaska, occur in California and western Nevada. The coastal areas of California are part of the active plate boundary between the Pacific and North American tectonic plates. Seismicity can be correlated with the well-known San Andreas fault system as well as many other active fault systems. A number of major earthquakes have occurred in this region; the most recent ones were the 1989 Loma Prieta and the 1992 Landers-Big Bear earthquakes. The following generalizations can be made: the earthquakes are nearly all shallow, usually less than 15 km (9 miles) in depth, the recurrence rate for a large (M_S greater than 7.8) earthquake on the San Andreas fault system is of the order of 100 years, the recurrence rates for large earthquakes on single fault segments in the Nevada seismic zone are believed to be in the order of thousands of years, and almost all of the major earthquakes have produced surface faulting.

Important Earthquakes of California and Western Nevada

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec. 21, 1812	Santa Barbara Channel	X	
June 10, 1836	Hayward fault, east of San Francisco Bay	IX-X	
June 1838	San Andreas fault	X	
Jan. 9, 1857	San Andreas fault, near Fort Tejon	X-XI	
Oct. 21, 1868	Hayward Fault, east of San Francisco Bay	IX-X	
Mar. 26, 1872	Owens Valley	X-XI	
Apr. 19, 1892	Vacaville, CA	IX	
Apr. 15, 1989	Mendocino County, CA	VIII-IX	
Dec. 25, 1899	San Jacinto, CA	IX	
Apr. 18, 1906	San Francisco, CA	XI	8.3
Oct. 3, 1915	Pleasant Valley, NV	X	7.7
Apr. 21, 1918	Riverside County, CA	IX	6.8
Mar. 10, 1922	Cholame Valley, CA	IX	6.5
Jan. 22, 1923	Off Cape Mendocino, CA	(IX)	7.3
June 29, 1925	Santa Barbara Channel	VIII-IX	6.5
Nov. 4, 1927	West of Point Arguello, CA	IX-X	7.3
Dec. 21, 1932	Cedar Mountain, NV	X	7.3
Mar. 11, 1933	Long Beach, CA	IX	6.3
May 19, 1940	Southeast of El Centro, CA	X	7.1
July 21, 1952	Kern County, CA	XI	7.7
July 6, 1954	East of Fallon, NV	IX	6.6
Aug. 24, 1954	East of Fallon, NV	IX	6.8
Dec. 16, 1954	Dixie Valley, NV (2 shocks)	X	7.3
Feb. 9, 1971	San Fernando, CA	XI	6.4
Oct. 15, 1979	Imperial Valley, CA	IX	6.6
May 2, 1983	Coalinga, CA	VIII	6.5
Oct. 1, 1987	Whittier Narrows, CA	VIII	6.1
Oct. 17, 1989	Loma Prieta, CA	VII	7.1
June 28, 1992	Landers, CA	VII	7.4
June 29, 1992	Big Bear, CA	VII	6.5
Jan. 17, 1994	Northridge, CA		6.6

WASHINGTON AND OREGON REGION

The Washington and Oregon region is characterized by a low to moderate level of seismicity in spite of the active volcanism of the Cascade range. With the exception of plate interaction between the North American and Pacific tectonic plates, there is no clear relationship between seismicity and geologic structure. From the list of important earthquakes that have occurred in the region, two of the three most recent damaging earthquakes in the Puget Sound area (M_S = 6.5 in 1965, M_S = 7.1 in 1949) occurred at a depth of 60 to 70 km. The third, the 1992 Petrolia earthquake (M_S = 7.1) occurred in the Mendocina triple junction where the Gorda, Pacific, and North American plates converge. Currently, speculation is occurring over whether a great earthquake can occur as a consequence of the interaction of these tectonic plates.

Important Earthquakes of Washington and Oregon

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Dec. 14, 1872	Near Lake Chelan, WA (probably shallow depth of focus)	IX	(7.0)
Oct. 12, 1877	Cascade Mountains, OR	VIII	
Mar. 7, 1893	Umatilla, OR	VII	7.0
Mar. 17, 1904	About 60 km NW of Seattle	VII	
Jan. 11, 1909	North of Seattle, near Washington/British Columbia border	VII	(5.7)
Dec. 6, 1918	Vancouver Island, B.C.	(VIII)	(5.8)
Jan. 24, 1920	Straits of Georgia	(VII)	
July 16, 1936	Northern OR, near Freewater	VII	
Nov. 13, 1939	NW of Olympia	VII	6.3
Apr. 29, 1945	About 50 km SE of Seattle	VII	
Feb. 15, 1946	About 35 km NNE of Tacoma (depth of focus 40-60 km)	VII	7.2
June 23, 1946	Vancouver Island	(VIII)	7.1
Apr. 13, 1949	Between Olympia and Tacoma (depth of focus about 70 km)	VIII	
Apr. 29, 1965	Between Tacoma and Seattle (depth of focus about 59 km)	VIII	6.5 7.1
Apr. 25, 1992	Petrolia (depth of focus about 10 km)	VII	

ALASKA REGION

The Alaska-Aleutian Island area is one of the most active seismic zones in the world. The Queen Charlotte Island-Fairweather fault system marks the active boundary in southeast Alaska where the Pacific plate slides past the North American plate. The entire coastal region of Alaska and the Aleutians have experienced extensive earthquake activity, even in the relatively short time period (85 years) for which the record of seismicity is well known. The most devastating earthquake in Alaska occurred on March 28, 1964, in the Prince William Sound. This earthquake, which has recently been assigned a moment magnitude of 9.2, also probably was the largest historical earthquake. It caused 114 deaths, principally as a result of the tsunami that followed the earthquake. The regional uplift and subsidence covered an area of more than 77,000 square miles.

Important Earthquakes of Alaska

Date	Location	Magnitude (Approx. M_S)
Sept. 4, 1899	Near Cape Yakatage	8.3
Sept. 10, 1899	Yakutat Bay	8.6
Oct. 9, 1900	Near Cape Yakatage	8.3
June 2, 1903	Shelikof Straight	8.3
Aug. 27, 1904	Near Rampart	8.3
Aug. 17, 1906	Near Amchitka Island	8.3
Mar. 7, 1929	Near Dutch Harbor	8.6
Nov. 10, 1938	East of Shumagin Islands	8.7
Aug. 22, 1949	Queen Charlotte Islands (Can.)	8.1
Mar. 9, 1957	Andreanof Islands	8.2
Mar. 28, 1964	Prince William Sound	8.4
Feb. 4, 1965	Rat Islands	7.8

HAWAIIAN ISLANDS REGION

The seismicity in the Hawaiian Islands is related to the well known volcanic activity and is primarily associated with the island of Hawaii. Although the seismicity has been recorded for only about 100 years, a number of important earthquakes have occurred since 1868. Tsunamis from local as well as distant earthquakes have impacted the islands, some having wave heights of as much as 15 meters (55 feet).

Important Earthquakes Causing Significant Damage in Hawaii

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Apr. 2, 1868	Near south coast of Hawaii	X	
Nov. 2, 1918	Mauna Loa, HI	VII	
Sept. 14, 1919	Kilauea, HI	VII	
Sept. 25, 1929	Kona, HI	VII	
Sept. 28, 1929	Hilo, HI	VII	
Oct. 5, 1929	Honualoa, HI	VII	6.5
Jan. 22, 1938	North of Maui	VIII	6.7
Sept. 25, 1941	Mauna Loa, HI	VII	6.0
Apr. 22, 1951	Kilauea, HI	VII	6.5
Aug. 21, 1951	Kona, HI	IX	6.9
Mar. 30, 1954	Near Kalapana, HI	VII	6.5
Mar. 27, 1955	Kilauea, HI	VII	
Apr. 26, 1973	Near northeast coast of Hawaii	VIII	6.3
Nov. 29, 1975	Near northeast coast of Hawaii	VIII	7.2
Nov. 16, 1983	Near Mauna Loa, HI		6.6

PUERTO RICO AND THE VIRGIN ISLANDS REGION

The seismicity in the Puerto Rico and Virgin Islands region is related to the interaction of the Caribbean and the North American tectonic plates. The Caribbean plate is believed to be nearly fixed while the North American plate is moving westward at the rate of about 2 cm/year. Earthquakes in this region are known to have caused damage as early as 1524-1528. During the past 120 years, major damaging earthquakes have occurred in 1867 and 1918; both earthquakes had tsunamis associated with them.

Important Earthquakes on or Near Puerto Rico

Date	Location	Maximum MMI (I_o)	Magnitude (Approx. M_S)
Apr. 20, 1824	St. Thomas, VI	(VII)	
Apr. 16, 1844	Probably north of PR	VII	
Nov. 28, 1846	Probably Mona Passage	VII	
Nov. 18, 1867	Virgin Islands (also tsunami)	VIII	
Mar. 17, 1868	Location uncertain	(VIII)	
Dec. 8, 1875	Near Arecibo, PR	VII	
Sept. 27, 1906	North of PR	VI-VII	
Apr. 24, 1916	Possibly Mona Passage	(VII)	
Oct. 11, 1918	Mona Passage (also tsunami)	VIII-IX	7.5

Appendix E

WHERE TO GO FOR INFORMATION

INTRODUCTION

This appendix is designed to provide the concerned individual and community with additional sources of information on various topics. It begins with a list of national, regional, and federal government sources of information on seismology, seismic design and construction, seismic building code provisions, and disaster assistance. A list of publications on various subjects addressed in this book appears next following by a list of Internet information sources. Much information is best obtained at the local level; therefore, the reader is urged to contact local academic institutions and the local chapters of the various professional, materials, and building officials' organizations as well as the national and regional sources named here.

NATIONAL AND REGIONAL ORGANIZATIONS

American Concrete Institute
P.O. Box 19150/22400 W. Seven Mile Road
Detroit, Michigan 48219-1849
(313)532-2600

American Consulting Engineers Council
1015 15th Street, N.W., Suite 802
Washington, D.C. 20005
(202)347-7474

American Forest and Paper Association
1250 Connecticut Avenue, N.W., Suite 200
Washington, D.C. 20036
(202)463-2700

American Institute of Architects
1735 New York Avenue, N.W.
Washington, D.C. 20006
(202)626-7300

American Institute for Architectural Research
1735 New York Avenue, N.W.
Washington, D.C. 20006
(202)879-7750

American Institute of Steel Construction
1 East Wacker Drive, Suite 3100
Chicago, Illinois 60601-2001
(312)670-2400

American Insurance Association
1130 Connecticut Avenue, N.W., 10th Floor
Washington, D.C. 20036
(202)828-7100

American Insurance Services Group, Inc.
85 John Street
New York, New York 10038
(212)669-0400

American Iron and Steel Institute
671 Newcastle Road, Suite 1
Newcastle, California 95658-9702
(916)663-1989

American Planning Association
1776 Massachusetts Avenue, N.W.
Washington, D.C. 20036-1997
(202)872-0611

American Plywood Association
7011 South 19th Street, Box 11700
Tacoma, Washington 98411-0700
(206)565-6600

American Public Works Association
Council of Emergency Management
1313 East 60th Street
Chicago, Illinois 60637
(312)667-2200

American Red Cross
National Office of Disaster Assistance
18th and E Streets, N.W.
Washington, D.C.
(202)857-3718

American Society of Civil Engineers
345 East 47th Street
New York, New York 10017
(212)705-7496

Applied Technology Council
555 Twin Dolphin Drive, Suite 550
Redwood City, California 94065
(415) 595-1542

Associated General Contractors of America
1957 E Street, N.W.
Washington, D.C. 20006
(202)393-2040

Association of Bay Area Governments
P.O. Box 2050
Oakland, California 94604
(510)464-7900
e-mail: jeanncp@abag.ca.gov

Association of Engineering Geologists
323 Boston Post Road, No. 2D
Sudbury, Massachusetts 01776
(617)443-4639

Association of Major City Building Officials
505 Huntmar Park Drive, Suite 210
Herndon, Virginia 22070
(703)437-0100

Association of the Wall and Ceiling Industries International
1600 Cameron Street
Alexandria, Virginia 22314-2705
(703)684-2924

Battelle Human Affairs Research Centers
4000 N.E. 41st Street
Seattle, Washington 98105
(206)525-3130

Brick Institute of America
11490 Commerce Park Drive, Suite 300
Reston, Virginia 22091-1532
(703)620-0010

Building Officials and Code Administrators International
4051 West Flossmoor Road
Country Club Hills, Illinois 60478-5795
(708)799-2300

Building Owners and Managers Association, International
1201 New York Avenue, N.W., Suite 300
Washington, D.C. 20005
(202)408-2662

Building Seismic Safety Council
1201 L Street, N.W., Suite 400
Washington, D.C. 20005
(202)289-7800
e-mail: cheider@nibs.org

Canadian National Committee on Earthquake Engineering
National Research Council of Canada
Division of Research Building
Ottawa, Ontario, Canada K1A 0R6
(416)996-5845

California Seismic Safety Commission
1900 K St., Suite 100
Sacramento, California 95814
(916)322-4917

Center for Earthquake Research and Information
Memphis State University
Memphis, Tennessee 38152
(901)678-2007
e-mail: stevens@ceri.memphis.edu

Center for Earthquake Studies
One University Plaza
Cape Gerardeau, Missouri 63701-4700
(314)651-2000

Central U.S. Earthquake Consortium
2630 E. Holmes Road
Memphis, Tennessee 38118-8007
e-mail: cusec@ceri.memphis.edu

Concrete Masonry Association of California and Nevada
6060 Sunrise Vista Drive, Suite 1875
Citrus Heights, California 95610
(916)722-1700

Concrete Reinforcing Steel Institute
933 North Plum Grove Road
Shaumburg, Illinois 60173-4758
(312)517-1200

Council of American Building Officials
5205 Leesburg Pike, Suite 708
Falls Church, Virginia 22041
(703)931-4533

Earthquake Engineering Research Center
University of California at Berkeley
1301 South 46th Street
Richmond, California 94844-4698
(415)231-9403
e-mail: eerclib@berkeley.edu

Earthquake Engineering Research Institute
449 14th St., Suite 320
Oakland, California 94612-1902
(510)451-0905

Earthquake Engineering Research Library
California Institute of Technology
Mail Code 104-44
Pasadena, California 91125
(818)395-4227
e-mail: eerlib@caltech.edu

Insurance Information Institute
110 Williams Street, 24th Floor
New York, New York 10038
(212)669-9200

Insurance Institute for Property Loss Reduction
73 Tremond Street, Suite 510
Boston, Massachusetts 02108-3910
(617)722-0200

International City Management Association
777 N. Capitol St., N.E.
Washington, D.C. 20002-4201
(202)289-4262

International Conference of Building Officials
5360 South Workman Mill Road
Whittier, California 90601
(213)699-0541

Masonry Institute of America
2550 Beverly Boulevard
Los Angeles, California 90057
(213)388-0472

Metal Building Manufacturers Association
1230 Keith Building
Cleveland, Ohio 44115-2180
(216)241-7333

National Association of Independent Insurers
2600 River Road
Des Plaines, Illinois 60018
(708)297-7800

National Association of Home Builders
15th and M Streets, N.W.
Washington, D.C. 20005
(202)822-0200

National Center for Earthquake Engineering Research
c/o Science and Engineering Laboratory.
SUNY-Buffalo
342 Copen Hall
Buffalo, New York 14260
(716)636-3379
e-mail: nernceer@ubvms.cc.buffalo.udc

National Committee on Property Insurance
10 Winthrop Square
Boston, Massachusetts 02110
(617)423-4620

National Concrete Masonry Association
2302 Horse Pen Road
Herndon, Virginia 22070-0781
(703)435-4900

National Conference of States on Buildings Codes and Standards
505 Huntmar Park Drive, Suite 201
Herndon, Virginia 22070
(703)437-0100

National Coordinating Council on Emergency Management
7297 Lee Highway, Suite N
Falls Church, Virginia 22042
(703)533-7672

National Elevator Industry, Inc.
185 Bridge Plaza, North, Suite 310
Ft. Lee, New Jersey 07024
(201)944-3211

National Emergency Managers Association
c/o Executive Director, Commonwealth of
P.O. Box 59
Kentucky, Department of Military Affairs, Division of Disaster and Emergency Services
Lexington, Kentucky 40501-0059
(502)564-8680

National Fire Sprinkler Association
Route 22 and Robin Hill Park, Box 1000
Patterson, New York 12563
(914)878-4200

National Institute of Building Sciences
1201 L Street, N.W., Suite 400
Washington, D.C. 20005
(202)289-7800

Natural Hazards Research and Applications Information Center
University of Colorado
Campus Box 482
Boulder, Colorado 80309-0482
(303)492-6818
e-mail: hazctr@colorado.edu

National Research Council Board on Natural Disasters
2101 Constitution Avenue, N.W., Room HA286
Washington, D.C. 20418
(202)334-1964
e-mail: cclarke@nas.edu

Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077
(312)966-6200

Precast/Prestressed Concrete Institute
175 West Jackson Boulevard, Suite 1859
Chicago, Illinois 60604
(312)786-0300

Rack Manufacturers Institute
8720 Red Oak Boulevard, Suite 201
Charlotte, North Carolina 28217
(704)522-8644

School Education Safety and Education Project
State Seismologist
Geophysics Department, AD-50
University of Washington
Seattle, Washington 98195
(206)545-7563

Seismological Society of America
201 Plaza Professional Building
El Cerrito, California 94530
(415)525-5474

Southern Building Code Congress International
900 Montclair Road
Birmingham, Alabama 35213
(205)591-1853

Steel Deck Institute, Inc.
P.O. Box 9506
Canton, Ohio 44711-9506
(216)493-7886

Steel Plate Fabricators Association, Inc.
2400 South Downing Avenue
Westchester, Illinois 60154-5102
(708)562-8750

Southeastern United States Seismic Safety Consortium
Department of Civil Engineering
The Citadel, The Military College of South Carolina
Charleston, South Carolina 29401
(803)792-7677

Southern California Earthquake Center
University of Southern California
University Park
Los Angeles, California 90089-0740
(213)740-5849
e-mail: jandrews@coda.usc.edu

The Masonry Society
2619 Spruce Street
Boulder, Colorado 80302
(303)939-9700

Western Seismic Safety Council
Washington State Department of Emergency Services
4220 East Martin Way
Olympia, Washington 98504
(206)459-9191

Western States Clay Products Association
9210 South, 5200 West
West Jordan, Utah 84084
(801)561-1471

Western States Seismic Policy Council
1995 Arizona Administrative Support Offices
Northern Arizona University
P.O. Box 4099
Flagstaff, Arizona 86011
(800)628-6754
e-mail: wsspc@vlshnu.glg.nau.edu

Utah Seismic Safety Commission
c/o Utah Geological Survey
2362 South Foothill Drive
Salt Lake City, Utah 84109
(801)467-7970

FEDERAL AGENCIES

Federal Emergency Management Agency

Mitigation Directorate, Program Development Branch
500 C Street, S.W.
Washington, D.C. 20472
(202)646-2794

Region I (Boston)
J. West McCormack Building, Room 442
Boston, Massachusetts 02109-4595
(617) 223-9540

Region II (New York)
26 Federal Plaza, Room 1338
New York, New York 10278-0002
(212) 255-7209

Region III (Philadelphia)
Liberty Square Building, 2nd Floor
105 S. Seventh Street
Philadelphia, Pennsylvania 19106-3316
(215) 931-5608

Region IV (Atlanta)
1371 Peachtree Street, N.E., Suite 700
Atlanta, Georgia 30309-3108
(404) 853-4200

Region V (Chicago)
175 West Jackson Boulevard, 4th Floor
Chicago, Illinois 60604-2698
(312) 408-5500

Region VI (Dallas)
Federal Regional Center, North Loop 288
Denton, Texas 76201-3698
(817) 898-5104

Region VII (Kansas City)
911 Walnut Street, Room 200
Kansas City, Missouri 64106
(816) 283-7061

Region VIII (Denver)
Denver Federal Center
Building 710, Box 25267
Denver, Colorado 80225-0267
(303) 235-4811

Region IX (San Francisco)
Building 105
Presidio of San Francisco
San Francisco, California 94129-1250
(414) 923-7100

Region X (Seattle)
Federal Regional Center
130 228th Street, S.W.
Bothell, Washington 98021-9796
(206) 487-4604

National Geophysical Data Center
National Oceanic and Atmospheric Administration
325 Broadway
Boulder, Colorado 80303
(303)497-6084

National Institute of Standards and Technology
Center for Building Technology
Room B168, Building 226
Gaithersburg, Maryland 20899
(301)975-5296
e-mail: dtodd@enh.nist.gov

National Science Foundation
Earthquake Systems
4201 Wilson Boulevard
Arlington, Virginia 22230
(703)306-1236
e-mail: Wanderso@nsf.gov

U.S. Geological Survey, Office of Earthquakes, Volcanoes and Engineering

905 National Center, M.S.101
12201 Sunrise Valley Drive
Reston, Virginia 22092
(703)648-4000

345 Middlefield Road
Menlo Park, California 94025
(415)853-8300

USGS National Earthquake Information Center
Denver Federal Center
Mail Stop 966, Box 25046
Denver Federal Center
Denver, Colorado 80225
(303)236-1586

PUBLICATIONS

The Earthquake Problem in General

Bolt, B. A. 1992. Earthquakes: a Primer . San Francisco, California: W. H. Freeman and Company.

Gere, J. M., and Shah, H. C. 1984. *Terra Non Firma: Understanding and Preparing for Earthquakes*. Stanford, California: Stanford University Alumni Association.

These two books are the best general surveys of the earthquake problem and very easy to understand. Bolt's book emphasizes the seismological aspects and Gere and Shah emphasize engineering, but both are comprehensive.

Levy, M., and Salvadori, M. 1995. *Why the Earth Quakes*. New York: W. W. Norton and Company.

This is a good general up-to-date survey of the world's earthquake problem and how engineers are dealing with it. It has been written by two distinguished engineers with a gift for simple explanation of technical issues.

Steinbrugge, K. 1882. *Earthquakes, Volcanoes, and Tsunamis, an Anatomy of Hazards*. New York: Skandia American Group.

This is a detailed but readable summary of the earthquake problem in the United States by one of the leading earthquake engineers and researchers.

The Seismic Hazard in the United States

For the information needed to define a specific location's seismic situation, contact local academic institutions for geologists, geophysicists and seismologists, state geologists, regional offices of the USGS and FEMA, national earthquake information centers, and state and regional seismic safety organizations. Also see the following section on Internet resources.

Algermissen, S. T. 1984. *An Introduction to the Seismicity of the United States*. Oakland, California: Earthquake Engineering Research Institute.

Seismic Codes and Provisions

For information about the seismic building code provisions in effect in a specific location, contact local building officials. Additional information is available from the three national model code groups: the Building Officials and Code Administrators International, the International Conference of Building Officials, and the Southern Building Code Congress International.

Federal Emergency Management Agency/Building Seismic Safety Council. 1994. *NEHRP Recommended Provisions for Seismic Regulations for New Buildings*, 2 volumes and maps, Publications 222A and 223A. Washington, D.C.: FEMA.

This is the current edition of this resource document. It is reflected in the seismic provisions of the model building codes and in the American Society of Civil Engineers national load standard.

Harris, James R. 1992. "An Overview of Seismic Codes." *Civil Engineering Practice* (Fall).

This is an excellent summary of the basis of seismic codes and their historical evolution.

Seismic Design

American Institute for Architectural Research. 1994. *Buildings at Risk: Seismic Design Basics for Practicing Architects*. Washington, D.C.: American Institute for Architectural Research.

This is a self-study course on seismic design for architects, but it provides a good overview of the subject for anyone interested in buildings. The materials include a videotape and an accompanying publication.

Arnold, C., and Reitherman, R. 1982. *Building Configuration and Seismic Design*. New York: John Wiley and Sons.

This is a summary of seismic design from an architectural viewpoint with emphasis on architectural decision-making as a determinant of seismic performance. It also contains a clear nontechnical explanation of the nature of ground motion and how it affects buildings.

Federal Emergency Management Agency/Building Seismic Safety Council. 1995. *Guide to Application of the 1991 NEHRP Recommended Provisions in Earthquake-Resistant Design of Buildings*, Publication 140. Washington, D.C.: FEMA.

This companion document to the 1991 Edition of the *NEHRP Recommended Provisions* is used in courses on application of the provisions requirements.

Federal Emergency Management Agency/Building Seismic Safety Council. 1995. *A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions*, Publication 99. Washington, D.C.: FEMA.

An introduction to the current edition of the *Provisions* for those without an engineering background.

Federal Emergency Management Agency. 1994. *Reducing the Risk of Nonstructural Earthquake Damage: A Practical Guide*, Publication 74. Washington, D.C.: FEMA.

This is a complete survey of the nonstructural problem aimed at building and facilities managers. It includes a clear explanation of earthquake effects on buildings and nonstructural components and systems.

Lagorio, H. J. 1990. *Earthquakes – An Architect's Guide to Nonstructural Seismic Hazards*. New York: John Wiley and Sons.

This book is an excellent general survey of seismic design, hazard, and risk from an architectural and planning viewpoint. The title is really a misnomer, however, because only one chapter on "nonstructural building elements" describes in detail types of damage to equipment and building contents and even this is more of a general survey of the problem.

Stratta, J. L. 1986, *Manual of Seismic Design,* Prentice-Hall, Englewood, NJ

This manual written by an experienced California engineer presents practical advice on seismic design for design professionals.

Reports on Significant Earthquakes and Earthquake Damage

Ayres, J. M., Sun, T. Y., and Brown, F. R. 1967. *Report on Nonstructural Damage to Buildings Due to the March 27, 1964, Alaska Earthquake*. Washington, D.C.: National Academy of Sciences.

Ayres, J. M., and Sun, T. Y. 1973. *Nonstructural Damage, San Fernando, California, Earthquake of February 9, 1971*, Vol. 1, Part B. Edited by L. M. Murphy. Washington, D.C.: National Oceanic and Atmospheric Administration.

These two documents are pioneer reports by a mechanical and electrical engineering team that, for the first time, showed the serious effects of earthquakes on the nonstructural components and systems of modern buildings. They remain the best studies on nonstructural earthquake damage that have been published.

Bennett, J. H., and Sherburne, R. W., Eds. 1983. *The 1983 Coalinga, California Earthquakes*, Special Publication 66. Sacramento: California Department of Conservation , Division of Mines and Geology.

California Seismic Safety Commission. 1995. *Turning Loss to Gain: the January 17, 1994 Northridge Earthquake.* Sacramento: California Seismic Safety Commission.

Earthquake Engineering Research Institute. 1980. *Reconnaissance Report, Imperial County, California, Earthquake of August 13, 1978.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1980. *Reconnaissance Report, Northern Kentucky Earthquake, July 27, 1980.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1983. *A Preliminary Report, Miramichi, New Brunswick, Canada, Earthquake Sequence of 1982.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1984. *Coalinga, California, Earthquake of May 2, 1983: Reconnaissance Report.* Oakland, California: EERI.

Earthquake Engineering Research Institute. 1988. "The 1985 Mexico Earthquake." *Earthquake Spectra* 4(3,5).

Earthquake Engineering Research Institute. 1988. "The Whittier Narrows Earthquake of October 1, 1987." *Earthquake Spectra* 4(1,2).

Earthquake Engineering Research Institute. 1990. "Loma Prieta Earthquake of October, 1989: Reconnaissance Report." *Earthquake Spectra,* Supplement to Vol. 6 (May).

Earthquake Engineering Research Institute. 1995. "Northridge Earthquake of January 17, 1994. Reconnaissance Report." *Earthquake Spectra*, Supplement C to Vol. 11 (April).

Earthquake Engineering Research Institute. 1995. "Nonstructural Damage, Chapter in Northridge Earthquake of January 17, 1994, Reconnaissance Report." *Earthquake Spectra,* Supplement C to Vol. 11 (April).

Earthquake Engineering Research Institute. 1995. *The Hyogo - Ken Nanbu Earthquake: Great Hanshin Earthquake Disaster January 17, 1995, Preliminary Reconnaissance Report.* Oakland, California: EERI.

Housner, George, Chairman. 1990, *Competing Against Time, Report to Governor Deukmejian from the Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake .* Sacramento, California: Governor's Board of Inquiry.

Jennings, P. C., Ed. 1971. *Engineering Features of the San Fernando Earthquake, February 9, 1971.* Pasadena: California Institute of Technology.

Moehle, J. P., Ed. 1994. *Preliminary Report on the Seismological and Engineering Aspects of the January 17, 1994 Northridge Earthquake.* Berkeley, California: Earthquake Engineering Research Center.

Murphy, L. 1973. *San Fernando, California, Earthquake of February 9, 1971.* Washington, D.C.: National Oceanic and Atmospheric Administration.

National Academy of Sciences Committee on the Alaska Earthquake. 1970. *The Great Alaska Earthquake of 1964.* Washington, D.C.: National Academy of Sciences.

National Institute of Standards and Technology. 1990. *Performance of Structures During the Loma Prieta Earthquake of October 17, 1989*, Publication 778. Washington, D.C.: U.S. Government Printing Office.

National Institute of Standards and Technology. 1994. *1994 Northridge Earthquake: Performance of Structures, Lifelines, and Fire Protection Systems*, Publication 5396. Washington, D.C.: U.S. Government Printing Office.

Nuttli, Otto, et al. 1986. *The 1886 Charleston, South Carolina, Earthquake – a 1986 Perspective*, Circular 98. Washington, D.C.: U.S. Geological Survey.

Oakeshott. G. B., Ed. 1975. *San Fernando , California, Earthquake of 9 February, 1971*, Bulletin 196. Sacramento: California Division of Mines and Geology.

Earthquake Loss Estimation Studies

Major loss estimation studies sponsored by governmental agencies are listed below. Some of these studies are now somewhat dated, but it is expected that a number of new studies will be conducted in the future once a new loss estimation methodology being developed for FEMA by the National Institute of Building Sciences is completed in 1996.

Davis, J. F., et al. 1982. *Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in the San Francisco Bay Area*, CDMG Special Publication 61. Sacramento: California Division of Mines and Geology.

Davis, J. F., et al. 1982. *Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California*, CDMG Special Publication 60. Sacramento: California Division of Mines and Geology.

Federal Emergency Management Agency. 1985. *An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from Earthquakes in the New Madrid Seismic Zone.* Washington, D.C.: FEMA.

Federal Emergency Management Agency/Central U.S. Earthquake Preparedness Project. 1990. *Estimated Future Earthquake Losses for St. Louis City and County, Missouri*, FEMA Publication 192, Earthquake Hazards Reduction Series 53. Washington, D.C.: FEMA.

National Oceanic and Atmospheric Administration. 1972. *A Study of Earthquake Losses in the San Francisco Bay Area: Data and Analysis.* Washington, D.C.: NOAA.

National Oceanic and Atmospheric Administration. 1973. *A Study of Earthquake Losses in the Los Angeles, California Area.* Washington, D.C.: NOAA.

Reichle, M. S., et al. 1990. *Planning Scenario for a Major Earthquake, San Diego-Tijuana Metropolitan Area*, CDMG Publication 100. Sacramento: California Division of Mines and Geology.

Steinbrugge, K. V., et al. 1987. *Earthquake Planning Scenario for a Magnitude 7.5 Earthquake on the Hayward Fault in the San Francisco Bay Area*, CDMG Special Publication 78. Sacramento: California Division of Mines and Geology.

Toppozada, T. R., et al. 1988. *Planning Scenario for a Major Earthquake on the Newport-Inglewood Fault Zone*, CDMG Special Publication 99. Sacramento: California Division of Mines and Geology.

U.S. Geological Survey. 1975. *A Study of Earthquake Losses in the Puget Sound, Washington Area*, USGS Open File Report 75-375. Washington, D.C.: USGS.

U.S. Geological Survey. 1976. *A Study of Earthquake Losses in Salt Lake City, Utah Area*, USGS Open File Report 76-89. Washington, D.C.: USGS.

U.S. Geological Survey. 1980. *Metropolitan San Francisco and Los Angeles Earthquake Loss Studies: 1980 Assessment*, USGS Open File Report 81-113. Washington, D.C.: USGS.

The Economics of Earthquakes

Federal Emergency Management Agency/VSP Associates. 1991. *A Benefit-Cost Model for the Seismic Rehabilitation of Hazardous Buildings*, FEMA Publications 227, 228, 255. Washington, D.C.: Federal Emergency Management Agency.

> These publications and their accompanying computer software enable the user to estimate the benefit-costs of rehabilitation programs for a variety of existing building types for any region in the United States. FEMA 227 and 228 deal with privately owned buildings and FEMA 255 covers federally owned buildings.

National Research Council Committee on Earthquake Engineering. 1992. *The Economic Consequences of a Catastrophic Earthquake*. Washington, D.C.: National Academy Press.

> This report includes a number of papers that review the economic impacts of large earthquakes. The focus is on indirect economic effects.

Weber, Stephen F. 1985. "Cost Impact of the *NEHRP Recommended Provisions* on the Design and Construction of Buildings." In *Societal Implications: Selected Readings*, Publication 84. Washington, D.C.: FEMA.

> This is the best reference to date for evaluating the effect on building design and construction costs of implementing seismic design.

Earthquake Hazard Mitigation Programs

Building Systems Development Inc. 1989. *Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings,* FEMA Publications 45 and 46. Washington, D.C.: Federal Emergency Management Agency.

> These reports focus on the kinds of programs that may be used to mitigate the hazard of existing buildings, how to establish priorities, and provides examples of programs that have been implemented.

INTERNET RESOURCES

World Wide Web (WWW) Sites

http://adder.colorado.edu/~hazctr/Home.html (be sure to spell "Home" with a capital "H")

The **Natural Hazards Research and Applications Center's Home Page** provides an introduction to the many programs and services provided by Hazards Center; current and back issues of the center's electronic newsletter, *Disaster Research*; our lists of hazard information sources and institutions, useful hazard periodicals, GIS hazard researchers, center publications, new books on hazards and disasters, upcoming hazards conference around the world; as well as an annotated inventory of other Internet resources.

http://www.fema.gov/

The **Federal Emergency Management Agency's Home Page** contains a lot of information (over 500 pages)-about the agency itself; current disaster situations; and disaster preparedness, response, recovery, and mitigation for families and businesses. The site includes dozens of hypertext links to other Internet resources via its Global Emergency Management Service (GEMS) page (http://www.fema.gov/fema/gems.html).

http://www.ngdc.noaa.gov/seg/hazard/hazards.html

The **National Geophysical Data Center (NGDC) Natural Hazards Data Page** includes databases, slide sets, and publications available from NGDC on geophysical hazards such as earthquakes, tsunamis, and volcanoes, as well as the *Natural Hazards Data Resources Directory* at (http://www.ngdc.noaa.gov/seg/hazard/resource/hazdir.html), published jointly with the Natural Hazards Center in 1990.

http://www/usgs.gov

The **U.S. Geological Survey Home Page** contains much useful information, including a natural hazards page (http:info.er.usgs.gov/research/environment/hazards/index.html) that provides information on earthquakes, volcanoes, coastal erosion, hurricanes, floods, and radon hazards.

http://www.fedworld.gov/

FedWorld is designed to provide a window to virtually all U.S. federal information services, including those dealing with disasters. It lists all agency Internet servers, provides access to the National Technical Information Service and the numerous reports available from that agency, as well as and many other federal reports.

Gophers

nisee.ce.berkeley.edu/1

The **Earthquake Information Gopher** maintained by the National Information Service on Earthquake Engineering (NISEE) offers information on all aspects of earthquakes and earthquake engineering, other organizations involved in earthquake hazard mitigation, and links to many other interesting gopher sites.

nceer.eng.buffalo.edu

The **National Center for Earthquake Engineering Research (NCEER) Gopher** presents even more general earthquake and earthquake engineering information, a raft of downloadable information, and access to NCEER's QUAKELINE database.

Lists/Newsletters/Discussion Groups

FEMA E-Mail News Service

To subscribe, send the e-mail message "subscribe news" to majordomo@fema.gov.

QUAKE-L

Quake-L includes discussions concerning recent earthquake events. To subscribe, send the e-mail message "subscribe QUAKE-L [your name]" to listserv@vml.noDak.edu.